Onboard Safety Systems Effectiveness Evaluation Final Report

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

October 2013

FOREWORD

The purpose of this project was to conduct a literature synthesis on three commonly deployed onboard safety system (OBSS) types and an effectiveness evaluation of these technologies using data collected directly from participating motor carriers. These OBSSs included lane departure warning (LDW), roll stability control (RSC), and forward collision warning (FCW) systems. The data acquired from participating carriers were used to answer three specific research questions: what are the safety benefits (i.e., reduction in the number of crashes) of LDW, RSC, and FCW systems regarding the specific crash types associated with each OBSS?; are these OBSSs cost-effective investments (e.g., what are the economic costs and benefits associated with adoption of each OBSS)?; and what are drivers' and safety managers' opinions and perceptions regarding each OBSS type?

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16. Abstract

The purpose of this project was to conduct a retrospective effectiveness evaluation study on three commonly deployed onboard safety system (OBSS) types using previous data acquired directly from participating motor carriers. These OBSS technologies included lane departure warning (LDW), roll stability control (RSC), and forward collision warning (FCW) systems. The current study assessed the effectiveness of these three different OBSS types installed on Class 7 and 8 trucks as they operated in their normal revenue-producing routes. Although the crash data were acquired from 14 carriers representing small, medium, and large carriers hauling a variety of commodities (including a total of 88,112 carrier crash records—USDOT-reportable accidents as well as minor incidents—and 151,624 truck-years of operation that represented 13 billion miles traveled), the dataset in the current study was skewed toward larger, for-hire carriers and may not fully represent the overall U.S. trucking population. The benefit-cost analyses clearly showed the estimated benefits of LDW and RSC systems deployed at participating fleets outweighed the estimated costs. The analysis of the fleet crash data using the same methodology did not show a statistically significant difference in FCW-related crash occurrence rates between vehicles with or without an FCW system installed. Retrospectively, this result is primarily attributed to the lack of sufficient data (in terms of number of trucks with a deployed FCW system in the dataset) to be able to detect safety benefits with statistical significance at the observed level. Focus groups were also conducted with drivers and safety managers who had experience with LDW, RSC, or FCW systems. Drivers' and safety managers' opinions and perceptions of each OBSS type were generally very positive.

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SI* (MODERN METRIC) CONVERSION FACTORS

Table of 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	1000 L 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 (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE	Temperature is in 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

Table of 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 (2000 lb)	T
		TEMPERATURE	Temperature is in 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 & 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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LIST OF ABBREVIATIONS AND ACRONYMS

ABS	anti-lock brake system
ACAS	automotive collision avoidance system
ACC	adaptive cruise control
ACE	average cost estimate
BCA	benefit-cost analysis
BCR	benefit-cost ratio
BSW	blind spot warning
CMBS	collision mitigation braking system
CMV	commercial motor vehicle
CRR	crash rate reduction
CWS	collision warning system
DF	degrees of freedom
EB	empirical Bayes
ECU	electronic control unit
EIA	Energy Information Administration
EPT	extended pilot test
ESC	electronic stability control
ESP	Electronic Stability Program
FCW	forward collision warning
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
FTP	file transfer protocol

GDP	gross domestic product
GEE	generalized estimating equation
GES	General Estimates System
HCE	high cost estimate
IRS	Internal Revenue Service
IVBSS	Integrated Vehicle-Based Safety System
km/h	kilometers per hour
LCE	low cost estimate
LDW	lane departure warning
MACRS	Modified Accelerated Cost Recovery System
mi/h	miles per hour
MOE	measure of effectiveness
MVMT	million vehicle miles traveled
NDA	non-disclosure agreement
NPV	net present value
OBSS	onboard safety system
ODLD	opposite direction lane departure
PATH	Partners for Advanced Transportation TecHnology
PDO	property damage only
PV	present value
QALY	quality-adjusted life years
RDCW	road departure crash warning
RSC	roll stability control
SAS	Statistical Analysis Software
SC	stability control

SEA	safety evaluation areas
SDLD	same direction lane departure
SVRD	single vehicle road departure
UMTRI	University of Michigan Transportation Research Institute
VMT	vehicle miles traveled
VORAD	vehicle onboard radar
VSL	values of statistical life
USDOT	U.S. Department of Transportation

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EXECUTIVE SUMMARY

The Federal Motor Carrier Safety Administration (FMCSA) is committed to reducing crashes, injuries, and fatalities involving commercial motor vehicle (CMV) transportation through education, innovation, regulation, enforcement, financial assistance, partnerships, and full accountability. One of the promising venues that supports FMCSA's safety mission is the expanded deployment of proven driver-assistance technologies. Working together with the trucking industry stakeholders, FMCSA envisions a future of smart technologies that support the increasing role of the trucking industry to safely, securely, and efficiently transport the Nation's goods and products.

In this research study, onboard safety systems (OBSS) of interest are vehicle-based driver assistance technologies that aim to improve the safety of in-service CMV operation. Today's modern trucks commonly feature one or more of OBSSs to help the driver mitigate or avoid a crash. Examples of commonly deployed OBSSs for CMVs include electronic stability control (ESC), roll stability control (RSC), lane departure warning (LDW), blind spot warning (BSW), forward collision warning (FCW), adaptive cruise control (ACC), and collision mitigation braking systems (CMBS). In-service effectiveness assessment of these systems is of significant importance to FMCSA, U.S. Department of Transportation (USDOT), fleets, safety advocacy groups and other industry stakeholders. This study not only augments the collective knowledge around the effectiveness of such OBSS systems, but it also helps faster deployment of these safety technologies at fleets by providing them a naturalistic basis of effectiveness measure from OBSS uses in real-life operational environments.

STUDY MOTIVATION

While there already is a wealth of literature on effectiveness assessment of OBSSs, these studies are primarily concerned with the effectiveness *estimations* or *projections* of the OBSSs based on engineering judgement, simulations, limited track, or field testing.

This research differs from existing OBSS effectiveness studies in that it statistically *measures* OBSS effectiveness in previous incident and accident records of participating fleets. Until recently, it was not possible to design a study of this nature because most of these OBSSs had only been newly introduced into the trucking industry, and furthermore, since crashes are rare events, many years of post-deployment operation was necessary to accumulate sufficient data to draw statistical conclusions over the safety impacts of their useage. Furthermore, this study is able to account for exposure in crash rate analysis based on vehicle miles traveled while previous studies did not have such ability.

It should also be noted that the observed effectiveness of OBSSs in this study refers to the measure of *in-service* effectiveness with the driver also in the loop. Drivers' immediate responses to generated warnings as well as longer term responses such as modifying their driving habits based on past system warnings or interventions can substantially influence the overall effectiveness observed with these OBSSs and resultantly, the in-service effectiveness results could differ from documented effectiveness results in the literature.

STUDY STRUCTURE

First, a generalized power analysis was followed to estimate the minimum number of vehicles with each OBSS type that would be needed in the dataset for statistical sufficiency.

Then, carriers were recruited to be able to achieve the necessary OBSS composition based on the power analysis. It was not possible to recruit enough fleets to achieve the necessary OBSS deployment numbers for many of the newer technologies. When the team recruited a sufficient number of fleets to be able to assess three of the more mature OBSS technologies with longer history, namely LDW, RSC, and FCW systems, they also assessed the amount of time and effort it would take to continue recruiting fleets to support analyses of other OBSS types. At that time, it was decided that such an effort would not be feasible within the framework of the research timeline, and hence the scope of this work was set to primarily cover LDW, RSC, and FCW systems.

A detailed literature survey of prior OBSS effectiveness studies was carried out for each of these three OBSS types. This effort benchmarked the expected ranges of reported effectiveness for each OBSS type of interest as well as previous benefit-cost analysis findings.

Concurrently, detailed carrier crash data were acquired from participating fleets. Data quality was assessed, non-conforming fleet data were identified and excluded from the dataset, and the remaining data were processed and harmonized into a single database across all fleets. During this stage, the team identified a need to statistically account for the existence of multiple OBSS systems on certain vehicles, which was not considered as a major factor at the beginning of the study. The effectiveness of the LDW, RSC, and FCW was, then, statistically analyzed in a retrospective manner, which established the in-field effectiveness measures for the subject OBSS types. When applicable, these measures were subsequently advanced into benefit-cost analyses for the carriers and for society.

In another track, drivers and safety managers from the participating fleets were interviewed to document the subjective user perceptions and opinions with these safety systems.

It should be highlighted that *the same methodology* was applied to each of the three OBSS types that were covered in this research, namely LDW, RSC, and FCW systems.

METHODS

Use of fleet *crash* data

This study uses carrier crash records for analysis. Carriers often have more stringent *crash* reporting requirements than *USDOT-reportable crashes* (see 49 CFR 390.5 and 390.15) and they include more minor *incidents* as well. Throughout this report, non-USDOT-reportable crashes (incidents) and USDOT-reportable crashes will collectively be referred to as *crashes* to be consistent with terminology carriers use.

As a direct result of the above, the overall crash rate in the dataset used as a basis for this study varied from 4.5 to 7.0 crashes per million vehicle miles traveled (MVMT), depending on the

OBSS cohort. This crash rate was far higher than the large truck crash rate reported in the National Highway Traffic Administration's *Traffic Safety Facts 2008* (1.36 crashes per MVMT). This does not reflect unsafe carriers, but rather a dataset that included a greater number and diversity of crashes than USDOT-reportable accidents alone.

Even with the rich dataset utilized in this study (151,624 truck-years equivalent operation), there was not an adequate number of USDOT-reportable accidents alone to draw statistical conclusions on the effectiveness of the three OBSSs. Inclusion of more minor crashes in the effectiveness analysis is consistent with procedures used in other studies where near-crash occurrences are typically included in the assessment of a system's benefits. Furthermore, the research team believes that the current carrier-collected dataset better represents motor carriers' crash costs and exposure than those severe enough to be reported to USDOT and included in the General Estimates System (GES).

Data Merging, Reduction

Recruitment of participating fleets with the required level of data and records management qualities was a major accomplishment of this study. Certain crash data elements were necessary to ensure all analyses were correctly performed (e.g., crash type, contributing factor, crash narrative, exposure, etc.). Participating carriers that did not collect the necessary data elements were not included in any analyses. Specific carrier information was also collected from each participating carrier. This information included carrier demographic information and safety management techniques. At a minimum, participating carriers provided 2 years of existing crash data from calendar years 2007–09 (all vehicles in the dataset were Class 7 and 8 trucks).

Within the qualifying pool of 14 suitable fleets, data from each fleet was harmonized into a single compatible database for analysis, which collectively accounted for 151,624 truck-years of operation, more than 13 billion miles of travel, and 88,112 crash records. The average mileage per truck per year was approximately 86,000 miles. Approximately 6 percent, 49 percent, and 4 percent of total truck-years of operation were accumulated with a LDW, RSC, and FCW system respectively.

Crash Association with OBSSs

Once data harmonization was complete, data analysts coded the crash type (using the existing crash type and crash narrative) using a uniform list of crash types created by the research team. The crash types coded by data analysts referred to the first impact in a crash. Using the crash narrative, crash type, and other data elements (e.g., contributing factor), data analysts also indicated if the crash was associated with an OBSS where that OBSS would have been effective. Even though this process had a subjective component, a rater reliability testing performed by the team yielded an inter-rater reliability of 96.4 percent and 99.7 percent on the designation of a crash type and its OBSS-relevance respectively.

Statistical Analysis

The main objective in the current study design was to quantitatively evaluate the safety impact of LDW, RSC, and FCW. Since it was possible to collect the OBSS status in all trucks in the dataset, a cohort study was preferred. And, because the current study was based on previous data, the overall study design was analogous to the classic retrospective cohort study. The formal statistical analysis to assess the safety benefit of each OBSS used a generalized linear model.[1] Specifically, the count based on the Poisson regression model was adopted to model the crash frequency with adjustment to exposure (MVMT). The modeling method also provided a way to control the confounding factors by including these in the model. One common problem with the Poisson regression-based safety model is the overdispersion issue (i.e., the variance is greater than the mean), and the research team addressed this issue by utilizing a common technique that includes a general estimation equation (GEE) implemented through an R-side random effect in statistical analysis software, which effectively accommodates the overdispersed data.

BENEFIT-COST ANALYSIS METHODS

The benefit-cost analyses (BCA) included a comprehensive list of known costs and benefits following conventional methods used in other similar studies. The research team performed BCA from both the carrier and the societal standpoints. The following cost and benefit items were considered in the study:

Costs:

- OBSS technology acquisition, installation, deployment, and financing costs,
- OBSS maintenance costs,
- OBSS replacement costs,
- OBSS training costs.

Benefits:

- OBSS investment-related Federal tax deduction savings for the carriers,
- Fleet Crash avoidance benefits including:
  - Labor and worker’s compensation,
  - Operational costs,
  - Environmental costs,
  - Property damage,
  - Legal settlement,
  - Court costs and other fees.
- Societal crash avoidance benefits including:
  - Medical-related costs,
  - Emergency response service costs,
  - Property damage,
  - Lost productivity,
  - Monetized value of pain, and the suffering and quality-of-life decrements experienced by families in a death or an injury.

The direct and indirect benefits associated with reductions in crashes with the use of an OBSS were compared to the costs of deploying each OBSS. Because information related to the costs of crashes was not available from participating carriers (given the time period involved in litigation and other factors), estimates of these costs were obtained from various government and insurance organizations. However, carriers supplied information on the costs associated with each OBSS.

FOCUS GROUPS

Although the primary evaluation in the current study related to the effectiveness of each OBSS, qualitative information on the acceptance and usage of these OBSSs by driver and safety management personnel was also assessed via focus group studies. Twelve focus groups (six with drivers and six with safety managers) were used in the current study, whereby there were four focus groups used for each LDW, RSC, and FCW at carriers that had the OBSS deployed in their fleets. Topics addressed in the focus groups included perceptions and opinions of each OBSS.

RESEARCH QUESTIONS

Data collected from participating carriers were used to answer three specific research questions:

- *Research Question 1:* What are the in-service safety benefits (i.e., reduction in frequency of crashes) observed with the use of each OBSS (i.e., LDW, RSC, and FCW) regarding the specific crash types associated with each OBSS?
- *Research Question 2:* Are these OBSSs cost-effective investments (e.g., what are the economic costs and benefits associated with adoption of each OBSS)?
- *Research Question 3:* What are drivers' and safety managers' opinions and perceptions regarding each OBSS?

SUMMARY OF STUDY RESULTS

Table 1, Table 2, and Table 3 summarize the safety benefit findings of this study on the three OBSS types, LDW, RSC, and FCW. The following sections further explain the main findings for each of these safety systems.

Table 1. Summary of Crash Statistics and OBSS Effectiveness Observations.

Type of Crash	LDW Equipped	Not LDW Equipped	RSC Equipped	Not RSC Equipped	FCW Equipped	Not FCW Equipped
Total Crashes	5,932	82,180	49,157	38,955	3,629	84,483
OBSS-Related Crashes	115	2,289	281	384	65	1,129
Truck-Years	12,597	139,027	74,398	77,226	9,788	141,836
Million Miles	1,156	11,910	7,059	6,007	814	12,252
Overall Crash Rate (per MVMT)	5.1	6.9	7.0	6.5	4.5	6.9

Table 2. OBSS Effectiveness Observation Summary: Overall OBSS-related Crash Rate Comparison.

Type of Crash	LDW Equipped	Not LDW Equipped	RSC Equipped	Not RSC Equipped	FCW Equipped	Not FCW Equipped
OBSS-Related Crash Rate (per MVMT)	0.099	0.192	0.04	0.064	0.08	0.092
OBSS-Related Crash Rate Reduction (per MVMT)	**48.4%** for LDW*	**48.4%** for LDW*	**37.5%** for RSC*	**37.5%** for RSC*	**13.1%** for FCW**	**13.1%** for FCW**

Note: Potential confounding effects due to existence of multiple OBSSs on a subset of trucks are ignored.
*Statistically significant.
**Not statistically significant.
†Statistical analysis results from Poisson GEE regression model are used throughout the report.

Table 3. OBSS Effectiveness Observation Summary: Poisson Generalized Estimating Equation (GEE) Regression Model Results.*

Type of Crash	LDW	RSC	FCW
OBSS-Related Crash Rate Ratio (without OBSS/with OBSS)	**1.917**	**1.555**	**0.997**
OBSS-Related Crash Rate Reduction (per MVMT)	**47.8%** for LDW*	**35.7%** for RSC*	**-0.3%** for FCW**

Note: Potential confounding effects due to existence of multiple OBSSs on a subset of trucks are discounted for each OBSS.

*Statistical analysis results from Poisson GEE regression model are used throughout the report.

Lane Departure Warning System Effectiveness

LDW system effectiveness analysis had sufficient statistical power in the analyzed dataset. Approximately 6 percent of the 13 billion (or 780,000,000) vehicle-miles accumulated were with a LDW system installed on the carrier vehicles.

The LDW system effectiveness analysis resulted in a statistically significant finding whereby trucks without LDW systems had a LDW-related crash rate (per MVMT) 1.917 times higher than trucks with such a system;

This reduction translates to a 47.8 percent crash rate reduction per MVMT in LDW-related crashes with the use of a LDW system, and this finding is on the high end of the range (23 percent to 50 percent) predicted in previous research studies that also assessed the effectiveness of LDW systems.[2,3,4,5,6] (Note that past studies reported reductions in the number of OBSS-related crashes and not the CRR per MVMT.)

A followup benefit-cost analysis showed the following:

- LDW system benefits to the carriers outweigh the costs by a factor (benefit-to cost ratio, or BCR) of 14.69 to 4.95 (depending on annual vehicle miles traveled [VMT]) implying a payback period of 4 to 12 months.

- LDW system benefits to society would outweigh the costs by a factor of 5.7 to 1.9 (depending on annual VMT) implying a payback period of 11 to 32 months.

The carrier BCR finding listed above associated with LDW effectiveness is higher than reported by Houser et al,[(3)] which was 6.55–1.37 (depending on VMT).

Roll Stability Control Effectiveness

RSC effectiveness analysis had very strong statistical power in the analyzed dataset in comparison to all OBSS systems deployed at the participating carriers. Approximately 49 percent of the 13 billion (or 6.4 billion) vehicle-miles accumulated were with a stability system installed on the carrier vehicles. Among the participating fleets, an overwhelming majority of the deployed stability control systems were RSC systems and a smaller subset were ESC systems, which was due to the nature of the supplier and system choice among the participating fleets and does not necessarily represent the market deployment ratio between these two stability control system types. The ESC subgroup alone did not have sufficient data to lend itself to a standalone statistical effectiveness analysis. As a result, this study only examined the RSC effectiveness.

The RSC effectiveness analysis resulted in a statistically significant finding whereby trucks without RSC systems had a RSC-related crash rate 1.555 times higher than trucks with such a system.

This reduction translates into a 37.5-percent crash rate reduction per MVMT in RSC-related crashes with RSC and it was on the lower half of the range (26 percent to 64 percent) predicted in previous research studies that also estimated the effectiveness of RSC systems.[(7,8,9)]

A followup benefit-cost analysis showed the following:

- RSC system benefits to the carriers outweigh the costs by a factor of 12.50 to 4.17 (depending on VMT) implying a payback period of 5 to 14 months.
- RSC system benefits to society outweigh the costs by a factor of 4.2 to 1.4 (depending on VMT) implying a payback period of 14 to 43 months.

Murray et al.,[(9)] estimated the carrier BCR using mandatory RSC deployment and found a BCR of 9.36–1.66. The carrier BCR in the current study was much higher than reported in Murray et al.[(9)]

Forward Collision Warning Effectiveness

At the beginning of the study it was concluded that, within the analyzed carrier dataset, data with FCW systems had sufficient statistical power to detect effectiveness within the upper end of the FCW effectiveness range of expectations from previous studies. Previous studies predicted 3 percent to 21 percent FCW-related crash reductions with the use of an FCW system. This goal was a goal for this study.

Later, a data-quality issue identified during analysis stages resulted in the omission of data from a big fleet, which primarily impacted the FCW effectiveness study's statistical power, significantly lowering the pool of vehicles equipped with an FCW system in the qualified dataset analyzed. At this stage, approximately 4 percent of the 13 billion (or 520,000,000) vehicle miles in the remaining qualified dataset were accumulated with an FCW system, which was lowest among all three OBSSs analyzed. There was borderline power left to potentially detect FCW effectiveness in the high end of the effectiveness spectrum. This was considered to be a possibility due to the following reason:

- There were primarily three types of FCW systems deployed at the participating fleets, a basic FCW system which was an older generation product, an ACC system which also includes the FCW functionality, and a CMBS product, which also includes both ACC and FCW functionalities. All three types of systems were projected to be effective in FCW-related crashes and hypothetical effectiveness would increase with FCW, ACC, and CMBS respectively. While none of these FCW system types had enough statistical power individually in the dataset, the team hypothesized that if they were collectively treated as a single FCW cohort, it might bias the harmonized effectiveness of the group towards the higher end of the expected effectiveness range since previous studies reported only expectations from basic FCW systems.

Hence, trucks equipped with FCW, ACC, and CMBS were treated as a single FCW cohort and analyzed collectively for effectiveness in FCW-related crashes.

This analysis yielded a *statistically non-significant effectiveness finding* for the FCW group. The FCW-related crash rates were practically indistinguishable between FCW and non-FCW cohorts, especially when the existence of multiple OBSS types on certain vehicles were discounted in the statistical analysis. This factor was not taken into account at the beginning of the study and the introduction of a new variant in the statistical analysis further diminished the statistical power of data for all OBSSs, but particularly affecting analysis with FCW, which already had borderline statistical power.

Retrospectively revisiting the power analysis, the dataset did not have enough statistical power to detect FCW effectiveness in this study in the expected range documented from previous studies.

Due to the lack of finding a statistically significant safety benefit with FCW systems in FCW-related crashes, benefit-cost analyses associated with FCW systems are determined not to be meaningful, and therefore, not included in this report.

Further research is recommended with FCW systems in general, particularly taking into account the generational differences in capabilities of such systems aiming to address FCW-related crashes, and with a particular focus on the more advanced versions of such systems currently available in the market place. A subgroup study performed by the research team implied that CMBS may have a particularly promising potential, but the dataset in this study did not have power to support a meaningful statistical analysis with that system.

DISCUSSION

The current study assessed the safety benefits of three different OBSSs 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 data collected directly from participating carriers; thus, the resultant dataset used in the analyses contained a broad spectrum of crashes (many 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 safety management techniques at the participating carriers, thereby allowing 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. Last, the research team reviewed each crash file to determine if the specific OBSS would have had a chance to mitigate a crash. The statistical analyses included a GEE Poisson regression to accommodate the potential overdispersion effect. The results across analyses indicated a strong, positive safety benefit for LDW and RSC, but were not statistically significant for FCW.

The lack of statistically significant findings for FCW was most likely due to statistical power issues at the expected effectiveness levels. It was projected that there was potentially borderline-sufficient statistical power to be able to detect FCW effectiveness in higher than expected range from previous studies but the results were statistically non-significant. There simply was not enough number of FCW-equipped vehicles in the dataset to be able to statistically detect safety benefits at the projected effectiveness levels.

While insufficiency of the FCW-relevant data in the dataset can explain the "statistical non-significance" of the observed safety benefits with FCW systems, the confounding effects of the driver being in the loop potentially affected the observed effectiveness levels. Previous FCW studies predicted a range of 3 percent to 21 percent effectiveness with the use of FCW systems but the high-end estimates were obtained assuming a perfect driver response (Fitch et al.,[(10)]) and marginal benefits were observed in naturalistic studies with the driver in the loop (Sayer et al,[(11)]). This study could be highlighting a similar effect, in statistically non-significant observations, whereby drivers' involvement in the loop may be lowering the in-service effectiveness of the deployed FCW systems.

GENERAL LIMITATIONS

Although the dataset used in the analyses to assess the effectiveness and cost-benefit of each OBSS was comprehensive, there were limitations.

- The crash files obtained from participating carriers could have contained errors. In turn, these errors could have influenced the effectiveness of each of the OBSSs and the cost-benefit analyses. There was no way to determine the veracity of the crash files.
- It was possible, albeit unlikely, that safety personnel at participating carriers with an OBSS may have been biased when populating the information in the crash file (e.g., assigning a different crash type and narrative to support the expense in purchasing the OBSS).
- Analysis was performed over all carrier required-to-be-reported crash data and not over only USDOT-reportable accidents. Because carrier crash data far outnumbered USDOT-reportable accidents, this fact may have caused the results to be skewed.
- The dataset in the current study was skewed toward larger, for-hire carriers and may not fully represent the overall U.S. trucking population (there was only one private fleet).

- Estimates of crash costs were used in the current study given the difficulty in obtaining actual crash costs (e.g., unwillingness of carriers to provide this information, time involved in litigation, etc.). It is possible these estimates misrepresent the actual crash costs and skew the cost-benefit analyses.
- Data analysts (although blind to the specific hypotheses) were not blind to cohort assignment, as they required this information to code OBSS-related crashes. As such, it is possible there was bias on the part of the data analysts (although the inter-rater reliability suggests otherwise).
- The research team had no information on the functionality of each OBSS installed on a truck [i.e., the research team could not verify if the OBSS was malfunctioning, tampered with, or engaged when applicable (e.g., ACC)].
- The LDW, RSC, and FCW systems in the current study were mostly older-generation systems; thus, the results may not reflect the effectiveness of newer generation systems.
- OBSS-related crashes may or may not have been a particular issue with the participating fleets who provided their data to the study and may or may not represent the entire effectiveness that may be observed at fleets which may be more or less prone to such risks.
- No driver information was collected; thus, it is possible that a few drivers were overrepresented in the crashes, and the difference in the OBSS-related crash rate may have been the result of these drivers and not the OBSSs.
- The choice (when applicable) of the vehicle for the installation of each OBSS was assumed to be random in the current study. No information was collected on the approach used by carriers to install the OBSSs. It is possible that carriers used a deliberate approach in selecting which trucks to install with an OBSS (e.g., only on new trucks or on vehicles operated by higher risk drivers).
- 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, there were several carriers that had trucks with and without a specific OBSS (thereby alleviating this issue).

CONCLUSIONS

The data used in the study were divided into two cohorts: trucks with an OBSS and trucks without an OBSS. The crash data were also arranged into two groups: crashes that were OBSS-related, and crashes that were not OBSS-related. The results across analyses indicated a strong, positive safety benefit for LDW and RSC. The benefit-cost analyses clearly showed the estimated benefits of LDW and RSC systems deployed at participating fleets outweighed the estimated costs.

The analysis of the fleet crash data using the same methodology did not show a statistically significant difference in FCW-related crash occurrence rates between vehicles with or without an FCW system installed. Retrospectively, this result is primarily attributed to the lack of sufficient data (in terms of number of trucks with a deployed FCW system in the dataset) to be able to detect safety benefits with statistical significance at the observed level.

A followup benefit-cost analysis showed the following:

- LDW system benefits to the carriers outweigh the costs by a factor (benefit-to cost ratio, or BCR) of 14.69 to 4.95 (depending on annual vehicle miles traveled [VMT]) implying a payback period of 4 to 12 months.
- LDW system benefits to society would outweigh the costs by a factor of 5.7 to 1.9 (depending on annual VMT) implying a payback period of 11 to 32 months.
- RSC system benefits to the carriers outweigh the costs by a factor of 12.50 to 4.17 (depending on VMT) implying a payback period of 5 to 14 months.
- RSC system benefits to society outweigh the costs by a factor of 4.2 to 1.4 (depending on VMT) implying a payback period of 14 to 43 months.

DRIVER AND SAFETY MANAGER OPINIONS AND PERCEPTIONS OF THE OBSS

Although the primary evaluation in the current study related to the effectiveness of each OBSS, qualitative information on the acceptance and usage of these OBSSs by driver and safety management personnel was also assessed via focus group studies.

Drivers' and safety managers' opinions and perceptions of each OBSS type were generally very positive. Overall, drivers and carrier staff liked having the OBSSs on their trucks; they believed the systems were beneficial and increased safety. Drivers and carrier staff believed the systems aided in keeping drivers alert and teaching them safe driving habits, such as maintaining a safe following distance, using their turn signals when making a lane change, and reducing their speed as they approached curves and turns. Both drivers and carrier staff recognized the relationship between safety, job retention, and company reputation; they appreciated how the OBSSs reflected their company's safety culture.

Based on the focus groups, there were several recommendations. Drivers and carrier staff agreed that OBSS training needed improvement and suggested giving drivers an opportunity to experience these systems in a simulator or controlled practice environment prior to making a revenue-producing delivery. Carrier staff suggested using driver testimonials in support of the OBSS to facilitate driver acceptance of these systems. Because drivers were curious about the technical functioning of these systems, training should be expanded to the functional capabilities and limitations of these systems.

Several recommendations concern the OBSS manufacturers. As carrier staff expressed concerns regarding the obsolescence of each OBSS, OBSS manufacturers should consider building scalable hardware devices that require software upgrades rather than new hardware purchases. Carrier staff requested easier access to the data collected by the OBSS to be able monitor their drivers. Enabling wireless downloads from the OBSS, rather than manual downloads, will allow more convenient access to data. Easier access to the data would enable carrier staff to monitor drivers more closely, provide feedback on their driving behavior, and implement targeted training to drivers, if needed. Lastly, drivers recommended the OBSSs include features that allow them to control the sensitivity of the OBSSs in certain situations and scenarios. For example, drivers could override the CMBS system in wet or icy conditions. However, carrier staff expressed concern that drivers may abuse these privileges and override the systems to the degree that these systems become ineffective (as they are always off).

FUTURE RESEARCH

Although the current study involved the collection of comprehensive truck, carrier, and crash 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 each OBSS. The current study design could be expanded to include a larger, more representative sample. Although there were 151,624 truck-years and 88,112 crashes in the dataset, the number of OBSS-related crashes represented a small proportion of these (4.8 percent of the total crashes). The results in the current study indicate that CMBS may be a promising technology. The current study was not designed to assess CMBS due to its limited deployment in the fleets that participated. Similarly, the study could not assess the effect of electronic stability control due to its limited deployment in the fleets that participated. Electronic stability control provides assistance during loss of control events in addition to roll stability control events, and further, due to its use of additional sensors, it could have higher overall rollover mitigation effectiveness than RSC systems alone.

1. BACKGROUND AND SIGNIFICANCE

1.1 INTRODUCTION

Safety is at the heart of the Federal Motor Carrier Safety Administration's (FMCSA) mission. Working together with the trucking industry, FMCSA envisions a future of smart technologies that support the expanding role of the industry to safely, securely, and efficiently transport the nation's goods and products. One way to save lives and reduce the number of injuries on the nation's highways is through the expanded use of proven or promising onboard safety systems (OBSS), such as: lane departure warning (LDW) systems, roll stability control (RSC) systems, and forward collision warning (FCW) systems. LDW systems are in-vehicle electronic systems that monitor the position of a vehicle within a roadway lane and warn a driver if the vehicle deviates or is about to deviate outside the lane. RSC systems monitor vehicle dynamics and estimate the stability of a vehicle based on its mass and velocity and actively reduce vehicle speed when a rollover risk is detected. FCW systems are in-vehicle electronic systems that monitor the roadway in front of the vehicle and warn the driver when a potential collision risk exists. Information from motor carriers about the effectiveness of these systems in improving safety will be valuable in advancing their further use in the trucking industry. The purpose of this project was to conduct a literature synthesis on the three OBSSs and an effectiveness evaluation of these technologies through the use of data collected directly from motor carriers. More specifically, the data collected from participating carriers were used to answer three specific research questions:

- *Research Question 1:* What are the safety benefits (i.e., reduction in the number of OBSS-related crashes) of LDW, RSC, and FCW regarding the specific crash types associated with each OBSS?
- *Research Question 2:* Are these OBSSs cost-effective investments (e.g., what are the economic costs and benefits associated with adoption of each OBSS)?
- *Research Question 3:* What are drivers' and safety managers' opinions and perceptions regarding each OBSS?

1.2 LITERATURE SYNTHESIS METHODS

1.2.1 General Approach

The general approach taken for the literature synthesis was to identify relevant documents from the broader research literature, and summarize the key information regarding measures of effectiveness (MOE) and system effectiveness using a structured review format. The corresponding review information was then synthesized into separate summaries identifying key MOEs and characterizing the overall effectiveness of each type of OBSS.

1.2.2 Literature Search

A literature search was conducted on each of the three OBSSs. The primary database used in the literature review was the Transportation Research Information System. Table 4 shows the keywords (or search terms) used in each initial OBSS search. The initial set of search results (as shown in Table 8) was reviewed to eliminate documents that could clearly be categorized as not relevant based on information available from the title and/or abstract. The remaining documents were ordered from various sources and included 68 documents relevant to RSC (note that stability control systems in general were reviewed), 32 to LDW, and 20 to FCW.

Table 4. Search Terms Used to Find Documents for Review

OBSS	Search Terms Used	Number of Documents Found
LDW	Road departure warning system, roadway departure warning system, and LDW system	90
RSC	Stability control, rollover stability control (RSC), roll stability	153
FCW	Forward collision warning, forward crash warning, headway warning	82

1.2.3 Document Summary Table

All documents obtained in the literature search were initially reviewed to determine if they contained information about the following: MOEs, system effectiveness, technology descriptions, or general background information. Documents that did not contain information about any of these fields were removed from further review. The remaining documents were organized in a summary table indicating the type of information provided, in addition to a field indicating whether they were reviewed in more detail (see Appendix A for a complete list of all the documents reviewed). The following fields were included in the Appendix A table:

- Reference: the document reference and Web link (if it was available online).
- Heavy Truck: the document addressed heavy truck issues.
- MOEs: the document provided information regarding MOEs.
- OBSS: the document provided information about the relevant OBSS.
- Other info: the document provided background or foundational information that was relevant to the review objectives.
- Reviewed: the document was reviewed in more detail.
- Not Reviewed: the document was not reviewed in detail.

Documents that did not provide information that were directly relevant to the review topics were not reviewed beyond the brief review they received when populating this table. This typically involved research sources that provided background information about particular technologies, such as how they should function or other technical aspects (as noted by the “Other Info” field), but not information about the topics covered in the review. These documents are indicated in the “Not Reviewed” column. In addition, several research efforts produced multiple reports, journal articles, and conference presentations. Where possible, priority was given to a final report or final version of the relevant project phase over journal articles and conference proceedings (which tend to provide less information). Typically, these secondary documents were either removed from the list or noted as duplicate works.

1.2.4 Document Reviews

For each technology, a subset of the most relevant documents was summarized in more detail using a structured format. A reviewer guide was developed and followed by research personnel conducting the document review. The reviewer guide is presented in Appendix B and a sample review form is shown in Figure 1. In total, detailed review summaries were conducted for 40 documents. These individual reviews, organized by type of OBSS, are provided in Appendix C.

Document:	
Safety System:	Vehicle Type:
Study Type:	
General Approach:	
Measures of Effectiveness:	
Quality:	Quality Note:
Applicability:	Applicability Note:
Key Findings and Recommendations: -	
Caveats/Comments:	

Figure 1. Image. Example of the Structured Review Form Used to Summarize Each Research Document.

The sections below provide a detailed summary of the information obtained in the document review. The Sections are organized by type of OBSS and include a review of MOEs (driver performance, driver acceptance, and safety benefits) and the efficacy of each OBSS**.**

1.2.5 Overview of LDW Research

The body of LDW research has focused primarily on light vehicles, with a limited number of studies related to heavy trucks and specialty vehicles (e.g., snowplows). Only the Integrated Vehicle-Based Safety System (IVBSS) effort provided information that directly addressed the MOEs and efficacy of LDW systems in heavy vehicles.(12) However, to date the IVBSS study has only produced limited results in the form of an extended pilot test.[(13)1] Given the emphasis on LDW systems in passenger vehicles, the discussion here on the MOEs and efficacy for LDW systems necessarily relies on passenger vehicle studies. Although there are important differences between the implementation of LDW systems in passenger vehicles versus heavy vehicles (e.g., driver populations and training, vehicle dynamics, cab environment, trip differences, and amount of driving), many of the principles that apply to the efficacy of LDW in passenger vehicles are also relevant to heavy trucks.

The LDW system research can be classified into four primary methodologies: field operation tests (FOTs), simulator and modeling studies, analytical studies (economic and safety benefits), and performance guidelines. Two FOT studies[(13,14)] provided the most salient information about key MOEs related to driver performance, including lane departures. Additional simulator and modeling studies[(15,16)] and an FOT related to snowplows[(17)] provided additional information that supported the findings in the primary FOTs. Analyses of economic and safety benefits[(18,19)] provided additional measures that support the use of LDW systems. The performance guidelines in Pomerleau et al.,[(5)] provided human factors information that can provide insights into the issues associated with the design and implementation of LDW systems.

1.2.5.1 Key Measures of Effectiveness for Assessing the Efficacy of LDW Technologies

Key MOEs for assessing the efficacy of LDW devices fall into three categories: driver performance, driver acceptance, and safety benefits. Each of these categories is discussed below in more detail.

1.2.5.2 Driver Performance Measures of Effectiveness

Number of Lane Excursions: This measure identifies the frequency with which the outer edge of the vehicle's wheel(s) crosses (or comes within a pre-defined distance of) a lane edge. This is a direct indicator of the effectiveness of the LDW system in preventing lane departures. Both FOT[(14)] and simulator[(15)] studies reported reductions in the number of lane excursions when using LDW versus driving without the LDW. In both studies, the number of lane excursions was reduced by 50 percent when driving with the LDW versus no LDW. Similarly, an independent evaluation of the road departure crash warning (RDCW) FOT[(20)] determined that the baseline lane excursion rate decreased by 31 percent.

Duration of Lane Departure: This measure refers to the amount of time spent driving out of the lane. When lane excursions do occur, the duration of lane departure indicates the amount of time the driver is exposed to potential conflict. LeBlanc et al.,[(14)] found that the amount of time during which the tire came within 4 inches of the lane edge was reduced by 63 percent when using the LDW system. Similar but less pronounced results were obtained in a passenger vehicle simulator study,[(15)] wherein drowsy drivers spent 20 percent less time out of lane during lane departures when LDW warnings were presented than they did without the warnings.

Number of Lane Changes with Turn Signal: This indirect MOE relies on the tendency of drivers to use their turn signals when changing lanes when the LDW system is active.[(14,21)] When

[1] The IVBSS pilot test used drivers that were associated with the project team and was intended to assess general system performance only. The research team included it here because of the paucity of LDW research.

drivers fail to activate the turn signal during a lane change maneuver, the LDW system assumes a lack of situational awareness and generates a warning alert as the vehicle approaches the lane edge. Therefore, activating the turn signal reduces the number of nuisance alarms presented to the driver.

Number of Valid Warnings: This MOE indicates how effectively drivers are paying attention to their lane position by monitoring how often conditions are met such that the LDW system activates an alert. In the IVBSS Extended Pilot Test (EPT),[(13)] the number of warnings decreased with increased use, which may indicate that drivers adjusted their driving style in order to reduce the number of alerts that were presented.

Lane-Keeping: Similar to the number of valid warnings measure, lane-keeping measures also indicate attention to lane position. LDW has been shown to improve overall lane-keeping performance. LeBlanc et al.,[(14)] found that the standard deviation of lane position decreased significantly when using the LDW system, indicating that drivers maintained a more consistent position within the lane under those conditions. Furthermore, drivers returned to the lane more quickly following imminent alerts compared with cases in which there were no LDW warnings.

1.2.5.3 Driver Acceptance Measures of Effectiveness

Number of Invalid Warnings: The number of invalid warnings can be used as a precursory measure of driver acceptance. Too many invalid warnings can result in both annoyance and a lack of trust in the system. In the IVBSS EPT,[(13)] drivers were neutral regarding the invalid alert rate of 5.5 alerts (total left and right LDW warnings) per 100 miles that was experienced in the IVBSS EPT.

Perception of Usefulness: This MOE is an indicator of how likely drivers may be to rely on the LDW system (drivers who do not expect the LDW system to be useful are less likely to use the system). This measure can relate to warning systems that exhibit low availability, as well as to how likely it is that the driver will respond to the warning. In the RDCW FOT,[(14)] drivers reported that 75 percent of LDW warnings were useful. They also reported that they thought they were better drivers while using the LDW system because they used cell phones less frequently and turn signals more often.

Perceived Benefit versus Liability: This measure is an indicator of how drivers and/or motor carrier supervisors expect the LDW systems to be beneficial or detrimental with regard to both safety and cost/savings. In a study of LDW systems for specialty vehicle operators (e.g., ambulance, state patrol cars, and snowplows), ambulance operators indicated they were reluctant to use the LDW system when a patient's life was at risk in an emergency driving situation.[(17)] Currently, it is unclear whether this measure will apply to heavy vehicles.

1.2.5.4 Safety Benefits

Crash Risk: Crash risk measures the relative crash involvement on a per-vehicle basis with and without LDW for a population of vehicles. This measure represents the true safety impacts that other MOEs generally try to approximate using indirect approaches. Crash risk is estimated by calculating a risk ratio that compares expected crash frequencies without LDW conditions to observed crash frequencies with LDW systems. Current research[(21)] identified potential lane departure scenarios in an analysis of the Large Truck Crash Causation Study.[22] However, no crash data were identified in the literature that were related to either heavy truck or passenger vehicle crashes while using LDW.

Cost-effectiveness: The cost-effectiveness of LDW was examined in a recent FMCSA report.[3] The crash reduction efficacy rates used in the analysis were based on field studies and industry input, and included a maximum of 53 percent and minimum of 23 percent crash prevention efficacy. Medium-sized to large carriers with an average likelihood of lane departure crashes were found to have achieved positive returns under all assumptions of vehicle miles traveled (VMT). The range of the positive return was $1.37–$6.55 for each dollar spent, depending on cost assumptions.However, the analysis also found that small carriers (with low deductibles and costs primarily covered by insurance) might not achieve direct cost recovery in the first 5 years, although lower long-term insurance rates and other less-tangible benefits (e.g., safety record) still make LDW worth considering.

1.2.5.5 Efficacy of LDW Technologies To Date

Two field studies in this area have assessed the overall efficacy of the LDW system. These include the IVBSS EPT,[13] which supports the larger, pending IVBSS FOT, and the RDCW FOT study.[14,19] Overall, LDW devices seem to have the potential for reducing lane departure/run-off-road collisions.[14,18,19] These devices seem to reduce the number and severity of lane excursions, improve overall lane keeping, and encourage the use of turn signals when changing lanes. In addition, drivers generally understand the meaning of the warnings and tend to react positively to these devices.

The following Section describes key findings relative to the efficacy of LDW warnings from the IVBSS EPT,[13] the RDCW FOT,[14,21] and FMCSA's benefit-cost analysis (BCA).[9]

Key findings relative to efficacy from the IVBSS EPT work[13] include:

- Both false and valid alert rates may be significantly affected by individual driving style. However, alert rates decreased with time, suggesting drivers changed their driving style to reduce the alert rate.
- In general, drivers responded positively to subjective questions related to system acceptance.
- Drivers' responses indicated the number of alerts they received were probably not inappropriate. One of the seven drivers indicated receiving too many LDWs, and two drivers indicated they received too few warnings.
- Most drivers understood the meaning of the LDWs.
- Driver responses were neutral regarding invalid LDW alerts. However, responses toward the invalid alerts in the integrated collision warning system (CWS) were negative.
- Although driver responses were generally favorable toward the integrated CWS, only two drivers indicated they would prefer to drive a truck with the CWS, as opposed to a truck without one. It is unclear whether drivers would maintain this opinion for a stand-alone LDW system.

Key findings relative to efficacy from the RDCW FOT[14,21] include:

- The number of lane excursions was reduced by 31 percent to 50 percent with LDW.
- Time spent in lane excursions was reduced by 63 percent.
- Turn signal use while changing lanes increased by 9 percent overall with a 23 percent increase in the quartile of drivers with the lowest rates of turn signal application per unit distance.
- A modest improvement in lane keeping (standard deviation of lane position) was observed when using the RDCW.
- With full deployment and 55 percent LDW availability, an annual reduction of 5,200 to 41,200 crashes would result.
- In general, drivers reacted favorably to the LDW portion of the overall RDCW. Drivers reported:
  - That 75 percent of LDW warnings were useful.
  - That they used cell phones less often and turn signals more often when LDW was enabled.
  - Infrequent concerns about receiving false alerts from the LDW.
  - They knew how to respond to an LDW alert.
  - The LDW made them more aware of their lane position.
  - They would pay an average of $500 for an independent LDW system.

The key finding relative to efficacy from FMCSA's BCA of LDW systems[3] is as follows:

- The benefits of using LDW systems over a period of 5 years outweighed the costs associated with purchasing the systems. For every dollar spent, carriers get more than a dollar back in benefits, ranging from $1.37 to $6.55.

1.2.6 Overview of Stability Control Research

Only a few available reports provided on-road evaluations of stability control (SC) in heavy trucks. The relevant data were primarily from studies describing two FOTs conducted in the early 2000's using SC systems.[23,24] In contrast, the large majority of the rollover research related to heavy trucks provided data that were useful as background information, such as engineering equations or information that was indirectly related to MOEs. In particular, these studies typically covered the underlying physics and parameters that had the greatest impact on rollover stability.[25,26,27] Although, some of this information could be useful for identifying MOEs, the review focused on related MOEs described in reports that involved actual implementations of SC systems[24,25] as these reports better reflected the practical constraints associated with implemented systems. (Note that earlier-generation SC systems involved warnings to the driver and either no or some rudimentary control over vehicle throttle and/or brake retardation. Newer-generation SC systems, such as the RSC systems assessed in this study, do involve warnings to the driver but use automatic control to mitigate stability risks.) Another large set of research sources addressed SC in light trucks and passenger vehicles. For the most part, these reports were only reviewed to determine whether or not they contained information that could be clearly applied to MOEs. An important consideration in this activity was the extent to which the information from passenger vehicles was applicable to heavy truck environments, and only those few that had elements that could be clearly applied were included in the literature synthesis. However, the full set of documents considered is included in Appendix A.

1.2.6.1 Key Measures of Effectiveness for Assessing the Efficacy of Stability Control Technologies

Several MOEs were identified for SC systems and these are separated into three categories. The first category covers engineering-related MOEs that are more directly related to the forces and conditions that reflect rollover risk conditions in real time, the second category covers driver-related MOEs (including driver performance and driver acceptance), and the third category covers safety and economic benefits.

1.2.6.2 Engineering Measures of Effectiveness

Lateral Acceleration: The first engineering MOE is lateral acceleration, which provides a direct measure of the principal force that precipitates rollover conditions. Lateral acceleration is simple to measure and is typically recorded at key locations on the tractor, trailer, or both. Lateral acceleration can be used to directly infer risky rollover conditions, or it can be used as input to more comprehensive measures, such as rollover risk indices (see description below). Lateral acceleration has also been used to measure some of the information cues that drivers may use during curve navigation. More specifically, in Winkler et al.,[(24)] lateral acceleration was measured at the driver's position in the cab to obtain information about how effective it may be as a cue (e.g., "gut feeling") about impending rollover risk during curve driving.

Lateral acceleration is often measured relative to the vertical plane, but a more relevant approach is to measure it relative to a plane parallel to the roadway surface, which takes into account geometric aspects of the roadway, such as superelevation.[(24)] Stevens et al.,[(28)] estimated that lateral acceleration based on speed and path curvature, but not road cross-section elements, reported substantially greater lateral acceleration levels than what was actually observed, with the difference attributed to curve superelevation. However, this phenomenon results in more conservative behavior from roll SC systems during such instances and does not compromise roll SC safety benefits.

Rollover Ratio: In its simplest form, the rollover ratio (or index) is the ratio of current lateral acceleration to the lateral acceleration that would be required to roll the truck at its current fill level in a static situation. The two different forms of this measure covered in this review vary with regard to how lateral acceleration is calculated, including the weighted average of tractor and trailer calculated by a simple yaw-plane model,[(24)] or lateral acceleration measured at the front axle.[(23)] In the Battelle[(23)] analysis, ratios between 55 percent and 80 percent were used to identify instances as potentially having some degree of rollover risk.

1.2.6.3 Driver-related Measures of Effectiveness

Speed entering a curve: This is simply a measure of the vehicle speed leading into a curve or turn. This is a useful driver performance indicator because, in most cases, speed is under the control of the driver in contrast to vehicle path, which is more limited by roadway geometry. This MOE can provide information about behavioral changes when curve speed is compared before and after SC activation. Note that this MOE is likely to be more informative with systems that provide direct advisory or warning messages that drivers can use to calibrate their behavior to the vehicle/system state.[29] However, it is also possible that drivers could infer this same information from noticeable aspects of vehicle performance under the control of SC systems (e.g., activation of engine brakes).

Driver Acceptance: A key objective for deploying SC systems reported in the reviewed documents is to provide a tool that helps drivers adopt safer driving habits. Two prerequisites for this are: drivers must "buy in" to SC system use and not try to undermine it (if system interventions are too frequent), and the information needed for drivers to understand that problem conditions are occurring is clearly communicated. These prerequisites can be measured by asking drivers qualitative questions, using surveys, interviews, ride-alongs, or focus groups, covering aspects such as ease of use, level of annoyance, and perceived usefulness, etc.

1.2.6.4 Safety and Economic Benefits

Crash Risk/Involvement: Crash risk measures relative crash involvement with and without an SC system on a per-vehicle basis. This measure represents the true safety impacts that other MOEs generally try to approximate using indirect approaches. Crash risk is estimated by calculating a risk ratio that compares expected crash frequencies without SC conditions to observed crash frequencies with SC.[30,31,32][2] Note that the key applicable information from these studies is the methodological and statistical approach since all data are based on passenger vehicles/light trucks and the crash types cover a greater range than those relevant to heavy truck SC systems.

Safety Benefits: Determining the safety benefits of SC systems involves using information about driver/vehicle performance with and without SC to estimate the overall change in expected crash rate. There are two key elements to this estimate. The first is the change in the probability that rollover conditions will occur (exposure ratio), and the second is, if rollover conditions do occur, how does the presence of the SC system affect the severity of the corresponding outcome (prevention ratio). More specifically, the exposure ratio reflects the ability of SC to reduce exposure to situations known to precede crashes, taking the distance traveled into account. It is simply calculated as the probability that a crash will occur with SC divided by the probability that a crash will occur without SC (controlling for total distance traveled). Thus, values significantly less than "1" represent positive reductions in crash exposure.

In contrast, the prevention ratio is a measure of the ability of an SC system to prevent or mitigate a crash once the crash-causing conditions have already occurred. For example, if a driver is entering a curve at a speed that will lead to a rollover, the question becomes how likely it is that the system will prevent a rollover from occurring relative to if no system is active. Accordingly, the prevention ratio is simply calculated as the probability that crash conditions with SC will lead

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[2] There were also additional reports that provided information about crash risk analysis that were not reviewed (e.g., Dang, 2007; Erke, 2008; Kreiss et al., 2005). As the key methodological information provided in these reports was already covered in other reviewed documents, they were not reviewed in light of available time and resources.

to an actual crash divided by the probability that crash conditions without SC will lead to an actual crash. Thus, values significantly less than "1" represent a reduction in crash severity. In the Battelle[(23)] analysis, the information needed to calculate the prevention ratio was derived using a computer simulation that determined how much additional speed would have been required to turn a conflict into an actual rollover crash, where applicable (e.g., only with full or partially full trailers since empty trailers would not have rolled over under most situations). This calculation was used as a proxy for actual crash severity.

1.2.6.5 Key Crash/Conflict Scenarios

Battelle[(23)] also identified a set of driving scenarios or conflicts that were most commonly associated with untripped rollover crashes and single-vehicle roadway departure crashes in heavy trucks. This information is potentially useful for focusing MOE data and analysis on the situations that are most relevant to the heavy-truck crashes that are likely to be addressed by SC systems. These scenarios are based on analysis of existing crash data available through the National Automotive Sampling System, the General Estimates System (GES), and the Fatality Analysis Reporting System, in addition to other insights provided by the fleet operator. Table 5 shows the driving scenarios or conflicts most commonly associated with untripped rollover crashes and single-vehicle roadway departure crashes (from Battelle[(23)]).

Table 5. Driving Scenarios or Conflicts Most Commonly Associated With Untripped Rollover Crashes and Single-Vehicle Roadway Departure Crashes

Crash Type	Driving Scenario	Heavy Truck	Tractor Trailer	Tanker Trailer
Rollover	Truck is turning or negotiating a curve at excessive speed and loses control	25%	25%	55%
Rollover	Truck loses control due to a vehicle-related failure	33%	32%	39%
Rollover	Truck is traveling at a constant speed and travels over the edge of the road	8%	5%	3%
Rollover	Truck is turning or negotiating a curve and travels over the edge of the road	3%	3%	0%
Rollover	Truck is traveling at a constant, excessive speed and loses control	3%	3%	0%
Rollover	Truck is traveling at constant speed and loses control due to poor road conditions	1%	1%	0%
Rollover	Truck is turning or negotiating a curve and loses control due to poor road conditions	1%	2%	0%
Single Vehicle Roadway Departure	Truck is turning or negotiating a curve and travels over the edge of the road	30%	37%	32%
Single Vehicle Roadway Departure	Truck is traveling at constant speed and travels over the edge of the road	16%	14%	14%
Single Vehicle Roadway Departure	Truck loses control due to vehicle-related failure	15%	14%	18%
Single Vehicle Roadway Departure	Truck is traveling at constant, excessive speed and loses control	4%	4%	3%
Single Vehicle Roadway Departure	Truck is turning or negotiating a curve at excessive speed and loses control	6%	6%	9%

Source: Battelle, 2003b

1.2.6.6 Efficacy of Stability Control Technologies

The following paragraphs characterize the efficacy of SC based on the MOEs described in the previous Section.

Lateral Acceleration and Rollover Index: Direct measures of SC effectiveness are limited since only two FOTs provide comprehensive data. Based on vehicle performance measures (such as lateral acceleration and rollover index in real-world settings), these data do not provide clear evidence of a meaningful degree of SC effectiveness in heavy trucks. One problem is that both FOTs were conducted with experienced and safety-conscious drivers, who did not drive in a risky manner. Consequently, the SC systems were not particularly challenged under real-world conditions. In particular, the Winkler et al.,[(24)] study found a small but statistically significant reduction in high-acceleration turning with SC; but most changes were minor and difficult to attribute to the SC system. Additionally, the Battelle[(23)] analysis indicated that SC did not activate during a risky maneuver during the FOT, primarily because drivers managed to avoid the conditions that would trigger the system. However, the occurrence of incidents in which the rollover index was greater than 55 percent was lower during the test phase than during the baseline phase (especially for higher index values). However, there were too few incidents overall to evaluate this measure statistically.

Driver Performance/Acceptance Measures: With regard to speed entering a curve, one FOT[(23)] found a small but statistically significant decrease in overall entry speed after a rollover warning was presented (except on ramps); however, no conclusive evidence was found that drivers who received a warning on a curve drove the same curve more slowly during subsequent encounters. In the Winkler et al.,[(24)] FOT, behavior in severe turns was significantly more conservative following warnings (especially within the first 250 kilometers of driving), which suggested the SC system was effective in promoting safer behavior. However, this effect may diminish over time as drivers get used to the system. Note that these findings were associated with older-generation SC "warning" systems.

One issue relevant to SC system efficacy was whether the presence of a "protective" system causes drivers to deliberately take on more risk than they otherwise would if no system was in place. In the case of SC systems, this could manifest as drivers are entering curves at high speeds or driving them under high lateral force (e.g., sharper turn) because they are implicitly relying on SC to compensate for increased risk. The Battelle[(23)] analysis looked for evidence of this possibility, either in performance data or through direct questioning of participant drivers. Although the driver fleet was probably more safety-conscious and experienced than typical drivers, there was no evidence of increased risk-taking behavior either in the performance data or from driver responses. Furthermore, design of newer active SC systems discourages drivers from pushing their vehicles beyond the limits of stability by slowing vehicles to a safe level when the SC system is engaged automatically.

With regard to driver acceptance, the studies that looked at this issue generally report positive results. More importantly, the SC system was not perceived as increasing workload or stress. Similarly, the Winkler[(24)] study reported that drivers appeared to embrace the utility of the SC; however, they also indicated the system had "some or little" influence on their driving. They also found the system simple to understand and the messages were clear, legibly presented, and not distracting.

1.2.6.7 Safety Benefits and Cost-Effectiveness

In particular, the SC system appeared to significantly reduce exposure to crash-causing situations; however, the estimated efficacy of the system in preventing crashes after those crash-causing situations occur (prevention ratio) was not significant. It was estimated that the SC system could prevent about 53 percent of rollovers attributable to excessive speed in curves.[(8)] Furthermore, combining SC with benefits from a driver advisory component resulted in an overall estimated reduction of 69 percent for those same types of crashes.

Cost-effectiveness of SC was examined in a recent FMCSA report.[(3)] The crash reduction efficacy rates used in the analysis were based on Houser, Pape, and McMillan,[(8)] and which included a maximum of 53 percent and minimum of 37 percent crash-prevention efficacy. Medium-sized to large carriers with an average likelihood of rollover crashes were found to have achieved positive returns under all VMT assumptions. The range of the positive return was $1.66–$9.36 for each dollar spent, depending on cost assumptions. It was also found that small carriers (with costs primarily covered by insurance) could achieve positive returns if one or more crashes are prevented. In contrast to this, Battelle[23] examined societal benefits relative to societal costs in implementing SC systems in various heavy truck types (greater than 10,000 pounds) and found mixed results. In particular, the societal benefits in terms of safety, mobility, efficiency, productivity, and environmental improvements in comparison to fleet-wide implementation and operation costs were found to be highest with tanker trailers, marginal for tractor trailers, and not cost-effective for large trucks. However, these estimates were based on an SC system that was less effective than more recent versions (as in Houser et al.,[8]); thus, the outcome likely underestimates the potential benefits in that analysis.

With regard to crash risk, there were no data that could be used to directly assess the effectiveness of SC in reducing heavy-truck rollovers under real-world conditions. However, findings from light trucks and passenger-vehicle studies can provide at least a general indication of potential effectiveness, keeping in mind that the results from this research are not directly applicable because they address different types of stability issues than are valid for heavy trucks, and the dynamics are very different. Crash data have been analyzed in several different studies; although there is some variation in how crash risk measures are calculated, the studies show crash risk reductions of around 54 percent to 70 percent in single-vehicle crashes. The effects are comparable when only fatal crashes are included, with crash risk reductions of 30 percent to 73 percent.[30,31,32,33] Overall, the effects are large enough that, although the physics are different, the general principle of mitigating operational factors that lead to rollovers clearly seems to be effective.

1.2.7 Overview of FCW Research

Past FCW research reflects a mix of passenger vehicle, heavy truck, bus, and specialty vehicle (e.g., snowplows) studies. Only the Volvo Field Operational Test (FOT) [34,35] and FMCSA's BCA of FCW Systems[36] have specifically examined the efficacy of FCW systems in heavy vehicles. The IVBSS effort had a heavy vehicle component that used FCW; however, results from this study were unavailable at the writing of this report. Given the emphasis on FCW systems in passenger vehicles, the discussion here on efficacy and MOEs for FCW devices necessarily relies on passenger vehicle studies. Although there are a number of important differences between FCW system implementations in passenger vehicles versus heavy trucks (including driver populations, vehicle dynamics, and trip differences), the MOEs discussed below are relevant and useful in the current project.

Most of the FCW research was conducted in the field; however, simulators were used in several of the studies. Most data sources do not provide detailed design data for the FCW device, although various generations of the Eaton vehicle onboard radar (VORAD) system have been used.[35] Zhang, Shladover, and Zhang[37] used off-the-shelf sensors and equipment to conduct an 11-month field study of FCW system efficacy in buses, and provide a useful description of the system architecture and components. In addition, a number of the studies featured integrated safety systems that bundled FCW with adaptive cruise control (ACC), making it difficult to draw conclusions about the efficacy of FCW alone.

The objectives and methodological approaches associated with the FCW-related studies have varied as well. Some studies,[38,39 ,40] have examined driver acceptance and performance issues in a controlled experimental setting in order to evaluate or refine design specifications for FCW devices. Design topics investigated in these studies have included alert timing, the format of alerting messages, and alert modality. A number of efforts[35,37,41,42] have examined the longer-term efficacy of FCW devices in a naturalistic field study. The FMCSA's BCA of FCW systems[36] obtained cost data from insurance companies and motor carriers related to crashes, labor, workers' compensation, operational costs, property damage, environmental damage, and legal fees in order to generate an estimate of cost savings associated with the installation of FCW devices. As discussed in more detail below, relevant MOEs are associated with each kind of FCW evaluation.

1.2.6.1 Key MOEs for Assessing the Efficacy of FCW Technologies

Key MOEs in assessing the efficacy of FCW systems fell into three categories: driver performance, driver acceptance, and safety benefits. These three categories are discussed in more detail below.

Driver Performance Measures of Effectiveness: Useful MOEs associated with driver performance have focused on both the driver's immediate response to a potential rear-end conflict, as well as longer-term behavioral measures related to safety. The driver's immediate response to a potential rear-end conflict is often a critical evaluation topic. For example, is the driver's reaction time (in terms of releasing the accelerator, braking, or a steering maneuver) to a rear-end conflict faster with an FCW device than without it? How does the FCW system change the driver's response with respect to deceleration rates (i.e., brake pressure) or rate of change in steering wheel angle? Obtaining these measures is often useful in FCW research as there is a limited amount of data on more direct measures of safety, such as vehicle crashes. Obtaining real-time, fine-grained measures of driver behavior can serve as proxies for crash data and allow researchers to make inferences about efficacy in the absence of crashes.

An example of a long-term measure of safety is the driver's following distances (or headway) with and without the system under comparable conditions. More specifically, is long-term exposure to the FCW system effective in promoting safer driving habits and increasing the driver's awareness of potentially unsafe situations? Other long-term measures of safety might be eyes-off-road time, speed relative to posted speed, or lane keeping. With these measures, the question is whether or not long-term exposure to the FCW system might lead to unintended consequences, such as less-attentive driving or driver neglect of routine safe driving behaviors.

Key driver performance MOEs include:

- Reaction time to a hazard or conflict (e.g., accelerator release, braking, steering maneuver).
- Deceleration rate, rate of change in steering.
- Following behaviors (distance or time gaps).
- Changes in visual scanning patterns, or dwell times.
- Speed decisions, lane-keeping behaviors.

Each of these driver performance MOEs requires some means of obtaining the relevant measures in real time and then storing the data for weeks or even months. An onboard data acquisition system, with appropriate sensors and storage devices, is typically installed in the FCW device and is able to record these data.

Driver Acceptance Measures of Effectiveness: MOEs reflecting driver perceptions of and reactions to the FCW system are valuable and necessary. Appropriately obtained driver acceptance measures can provide useful insights into the benefits and problems with OBSSs that will not be apparent from measures that are more objective. For example, a number of the FCW research studies have asked drivers about the prevalence and impact of false/nuisance alerts and determined that a large number, sometimes a majority, of alerts are perceived by drivers to be false/nuisance alerts.(43) False/nuisance alerts can lead to decreased trust in the system and a desire to turn the FCW system off.(42) Thus, some information about use and, ultimately, the efficacy of FCW systems, can be obtained quickly and efficiently through assessments of driver acceptance.

Driver acceptance measures are typically obtained through one of several methods, including: structured questionnaires/surveys (paper and pencil, computer-based, online), interviews (telephone or in-person), ride-alongs, and/or focus groups. Driver acceptance measures using these methods include perceptions related to:

- Ease-of-use.
- Ease-of-learning.
- Perceived value and utility.
- Understanding of how the system works.
- Appropriateness, timing, frequency, location, modality, comprehension, and format of individual alerts.
- Workload, distraction, errors associated with alert presentation.
- Accuracy and reliability of the system.
- How the system could be improved.

Safety Benefits: Determining the safety benefits involves using information about driver/vehicle performance with and without the FCW system to estimate the change in expected crash rate or rear-end conflicts. Actual crashes as a function of VMT are often used in this type of analysis. Given the relative infrequency of actual crashes, near misses are often calculated as well. Thus, both exposure and outcome measures are obtained and assessed. The goal is to provide quantitative, objective estimates of FCW system effectiveness in reducing the number of crashes and near misses as well as to evaluate changes in the probability of crashes across various FCW scenarios (see Najm et al., 2006(42) for a more complete discussion of calculating safety benefits for FCW systems).

Safety benefits are often assessed within the larger context of a BCA,(35,36,42) in which the total costs associated with purchasing, installing, using, and maintaining an FCW device are compared to the benefits associated with the systems. Measures include the number of crashes the FCW devices could prevent as a function of VMT over a certain period of time. Other cost items that can be examined[36] include labor, workers' compensation, operational costs, property damage, environmental damage, and legal costs, etc., associated with crashes.

Additional Thoughts on Measures of Effectiveness: A key requirement of MOEs is that the measures be obtained both with and without the FCW system under comparable conditions. Thus, the overall efficacy of a particular FCW device always reflects driver performance, acceptance, and overall safety relative to driving without the device. In a typical FOT, for example, baseline driving data (i.e., driving without the system for a period of time) are obtained and then compared to the same data with the system in use. In some cases, previous data on crash rates, as a function of exposure or VMT, are compared to crash rates with the FCW system. Individual research studies will vary with respect to their ability to obtain baseline data, or on the precise measures with which before/after data can be obtained. Properly measuring efficacy, however, always requires a rigorous comparison between driving data obtained with and without the FCW device.

1.2.6.2 Efficacy of FCW System Technologies To Date

Several studies in this area have assessed the overall efficacy of the FCW system. These include the University of Michigan Transportation Research Institute's (UMTRI) automotive collision avoidance system (ACAS) study,[41,42,43] Battelle's evaluation of the Volvo FOT,[34,35] the California Partners for Advanced Transportation TecHnology (PATH) investigation of FCW efficacy on buses,[37] and FMCSA's analysis of costs and benefits of FCW systems.[36] Overall, FCW devices seem to have the potential for reducing rear-end collisions, with potential reductions in crashes ranging from 3 percent[42] to 21 percent.[34] FCW devices also seem to aid drivers in maintaining increased headways from the vehicle ahead. In addition, drivers generally react favorably to FCW devices; however, high false alarm rates are likely to reduce driver acceptance.

Key findings related to efficacy from the UMTRI ACAS study[41,42,43] include:

- Increased headways with FCW enabled.
- FCW has the ability to prevent about 10 percent of all rear-end crashes (somewhere between 3 percent and 17 percent).
- Driver acceptance data were mixed (driver opinion was positive when the FCW system warned drivers of actual threats). Less than half of the drivers indicated an interest in purchasing the system.
- False/nuisance alarms were a problem (41 percent of the participants would have used an on-off switch if one had been available).
- The majority of alerts were perceived to have been either unnecessary or a nuisance, fostering poor driver acceptance and trust. Only 27 percent of all imminent alerts were triggered by events requiring driver intervention to resolve a developing conflict.
- Since drivers became aware the FCW alerts often occurred in situations in which braking was not required, they did not brake reflexively to imminent FCW alerts.

Key findings related to efficacy from the Volvo FOT(34,35) include:

- The FCW system reduced the risk of a rear-end collision by 21 percent and helped drivers maintain longer following distances.
- Overall, drivers reported no major problems with the FCW system and had a positive reaction to the system. The system did not seem to present a distraction, though drivers disliked nuisance alerts. Drivers understood the FCW system and its potential benefits. Drivers believed the technology helped them drive more safely.
- Overall economic benefits were observed, but only if the costs of the technology were reduced in the future.

Key findings related to efficacy from the California PATH investigation of FCW in buses include:[3]

- FCW led to more consistent and generally safer driving behaviors.
- Individual driver differences were most noticeable in the car-following time gaps.
- Drivers showed different preferences for sensitivity levels when the drivers were allowed to make such adjustments.

The key finding related to efficacy from FMCSA's BCA of FCW systems(36) is as follows:

- The benefits of using FCW systems over a 5-year period outweighed the costs associated with purchasing the systems. For every dollar spent, carriers get more than a dollar back in benefits, ranging from $1.33 to $7.22.

[3] Note that data from only seven drivers were used in the analyses, and that the limited time available to conduct data collection did not allow for the assessment of additional safety benefits.

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2. METHODS AND APPROACH

This chapter outlines methods used to collect quantitative and qualitative data in the current study.

2.1 DATA COLLECTION PROCEDURES

There were two data collection efforts in the current study. The first involved the collection of existing carrier-owned data by the research team to assess the effectiveness of LDW, RSC, and FCW, and the second effort involved the collection of new information from drivers and carrier management personnel at participating carriers to assess qualitative information on each OBSS (e.g., acceptance, usage, etc.). Carriers that did not have these OBSSs were recruited to participate as comparison carriers in the effectiveness evaluation. These two efforts are described in more detail below.

2.1.1 Carrier-Owned Data

First, a general power analysis was performed to determine the minimum number of vehicles with each OBSS type that would be needed in the dataset for statistical sufficiency. Then, carriers were recruited to be able to achieve the necessary OBSS composition based on the power analysis. It was not possible to recruit enough fleets to achieve the necessary OBSS deployment numbers for many of the newer technologies. When the team recruited sufficient number of fleets to be able to assess three of the more mature OBSS technologies with longer history, namely LDW, RSC and FCW systems, they also assessed the amount of time and effort it would take to continue recruiting fleets to support analyses of other OBSS types. At that time, it was decided that such an effort would not be feasible within the framework of the research timeline and hence the scope of this work was set to primarily cover LDW, RSC and FCW systems.

The research team collected existing motor carrier data from participating carriers to evaluate the effectiveness of LDW, RSC, and FCW. The research team also included trucks installed with **c**ollision mitigation braking systems (CMBS) and ACC. CMBSs are FCW type systems that also automatically engage the truck's brakes to prevent or reduce the impact of rear-end collisions. ACC are FCW type systems that also automatically maintain a safe following distance between the truck and the lead vehicle when activated. More specifically, FCW, ACC, and CMBSs were expected to reduce rear-end collisions in which the truck is striking another vehicle (and, to a lesser extent, head-on collisions); LDW was expected to reduce single-vehicle roadway departures, same direction lane departures (SDLDs), and opposite direction lane departures (ODLDs); and RSC was expected to reduce rollover crashes involving combination trucks. Data on the cost-benefits of each OBSS were also collected. The direct and indirect costs associated with reductions in crashes were compared to the costs of each OBSS. As information related to the costs of crashes was not available from participating carriers (given the time period involved in litigation and other factors), estimates of these costs were obtained from various government and insurance organizations. However, carriers supplied information on the costs associated with each OBSS.

This study uses carrier crash records for analysis. Carriers often have more stringent crash reporting requirements than USDOT-reportable accidents [as defined in 49 CFR 390.5 and as reported per 49 CFR 390.15] and they include more minor incidents as well. Throughout this report, non-USDOT reportable crashes (incidents) and USDOT-reportable accidents will collectively be referred to as crashes just as carriers do. [It was neither within the scope of work to compare USDOT-reportable crashes with all reported crashes nor to conduct a separate subanalysis of the USDOT-reportable crashes.]

Certain data elements were necessary to ensure the OBSS effectiveness evaluation was performed correctly. Carriers that did not collect the necessary data elements were not included in any analyses. Specific carrier information was collected from each participating carrier. This information included carrier demographic information and safety management techniques (see Appendix D for the Carrier Demographic and Information Sheet). Crash data were collected from carriers that were able to provide at least 2 years of existing crash data from calendar years 2007–09 (all vehicles in the dataset were Class 7 and 8 trucks). Only one carrier had 2010 crash data. Below is a list of data elements that were requested from participating carriers in order to assess the safety benefits of each OBSS.

- Crash Information.
  - *Date (*denotes a required data element).
  - State.
  - Location (e.g., mile marker on I-81).
  - Contributing factor (e.g., excessive speed).
  - Time of day.
  - Hours since last break.
  - *Preventable (yes/no).
  - *USDOT-reportable (yes/no).
  - Weight of load.
  - Heavy haul (yes/no).
  - *Number of combination units.
  - Road type (e.g., State highway).
  - *Crash type (e.g., rollover).
  - *Crash narrative.
  - *Injury (yes/no).
  - *Fatality (yes/no).
- Vehicle Information.
  - *Vehicle year (e.g., 2008).
  - *Mileage.
  - Anti-lock brakes (yes/no).

  - *Vehicle number or identifier.
    - *OBSS.
    - Model.
  - Manufacturer.
  - Speed limiter setting (date and setting, if changed).
- Carrier Information.
  - SafeStat Score.
  - Fuel efficiency bonus.
  - Fleet type (e.g., for hire: long haul).
  - Commodities hauled (e.g., general freight truckload).
  - Safety management techniques.

2.1.1.1 OBSS Carrier-Selection Criteria

The technology review was performed to determine the current state of technologies for LDW, RSC, ACC, and CMBS. This review generally provided a summary of OBSS technologies that were currently available or will be available in the near future. A complete list of OBSSs (for both passenger cars and heavy trucks) can be found in Appendix E. A literature search was conducted to identify specific technologies to be included in the effectiveness evaluation. Sources included books, trade journals, product brochures, manufacturers' press releases, manufacturers' Web sites, and trade magazine Web sites. Candidate technologies were then evaluated for appropriateness of inclusion, as described below. Technologies deemed out of date or inappropriate were removed from further consideration. After identifying the products to be included, the literature was reviewed to determine the characteristics of each OBSS technology, including product type, target market, and functional specifications. Wherever possible, the makes and models of vehicles equipped with the technology were identified. In addition, information regarding collaboration of efforts between companies, either for joint product development or for production, was identified.

OBSS technologies were chosen for inclusion in the review based on relevance and on product availability. Products that were currently available or were expected to be available by the year 2010 were included in the review. In addition, OBSS technologies that were mature enough to be demonstrated on a concept car or truck were included in the review. Older products that were no longer available, evolved into a different product, or had been purchased by another vendor were excluded from the review. Only complete OBSS devices were included in the review; technologies that were strictly component parts of a larger system (e.g., radar to be sold for inclusion in an FCW) were excluded from the review.

2.1.1.2 Carrier Recruitment

The research team recruited fleets based on the carrier selection recommendations outlined above, including: having the required data elements, sufficient data (i.e., at least 2 calendar years of data), and an OBSS noted in Appendix E or an emerging OBSS not included in Appendix E (if the carrier had an OBSS). The research team cultivated relationships with many different motor carriers; these carriers were contacted via email and/or phone to determine if they met the necessary selection criteria for participating in the current study and, if they did, to request participation. To increase participation, an advertisement was placed in *Transport Topics* requesting participation from interested carriers.

2.1.1.3 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. Carriers sent the research team a spreadsheet (via email, on a compact disk via the U.S. Postal Service, or via file transfer protocol (FTP) transfer) with carrier-collected crash and non-crash data (trucks that were not involved in a crash). This usually involved an iterative process as certain data variables were missing and/or further explanation was needed regarding the meaning of codes included in the dataset. Specific carrier information was also collected from these carrier representatives. This information included carrier demographic information, safety management techniques, and costs associated with each OBSS (where necessary). This information was crucial in controlling for differences between carriers. See Appendix D for the Carrier Demographic and Information Sheet.

2.1.1.4 Data Merging/Reduction

As the datasets provided by each carrier were not identical, all datasets were merged and formatted into one large dataset with common headings. Once this was complete, data analysts 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 5 displays the operational definitions for the uniform crash types and whether these crash types could have been prevented or mitigated by one of the OBSSs. The crash types coded by data analysts referred to the first impact (e.g., a vehicle that encroached 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 6. Operational Definitions for the Uniform Crash Types Created by the Research Team

Crash Type	Operational Definition	OBSS
Run Off Road	The truck runs off the road and the road and/or surface causes damage to the truck.	LDW
Head On	The truck had a head-on collision with another vehicle on the roadway.	FCW/LDW
Rear-End	The truck rear-ended another vehicle on the roadway.	FCW
Rear-Ended	The truck was rear-ended by another vehicle on the roadway.	n/a
Sideswipe	The truck struck another vehicle/object traveling in the same direction on its side.	LDW
Opposite Sideswipe	The truck struck another vehicle/object traveling in the opposite direction on its side.	LDW
Backing	The truck was backing up and struck another vehicle or object.	n/a
Parking Lot	The truck strikes a fixed object or vehicle while maneuvering in a parking lot, dock, or truck stop.	n/a
Hit Object in Road	The truck hits an object in the roadway while driving.	n/a
Hit Animal	The truck strikes an animal in the roadway.	n/a
Rollover	The first impact is the truck rolling over.	RSC
Jackknife	The first impact is the truck jackknifing (loss of control of the trailer).	n/a
Parked	Another vehicle, person, or object damages the truck while it is parked.	n/a /A
Roll Back	The truck rolls back into another vehicle or object after releasing the brake.	n/a
Roll Away	The truck rolls forward into another vehicle or object after releasing the brake.	n/a
Hit Fixed Object	The truck strikes a fixed object that is not on the roadway.	n/a
Hit Pedestrian	The truck strikes a person.	n/a
Overhead	The truck strikes an overhead object (e.g., an overpass).	n/a
Mechanical	The truck experiences some sort of mechanical failure and it strikes another vehicle, object, or person.	n/a
Hit by Other Vehicle (OV)	Another vehicle strikes the truck, but there was not enough information to classify a specific crash type.	n/a
Truck Hit Other Vehicle	The truck strikes another vehicle, but there was not enough information to classify a specific crash type.	n/a
Broadside	The truck T-bones another vehicle or when the other vehicle T-bones the truck.	n/a
Other	Miscellaneous crash circumstances that do not fit into other categories.	n/a
Non-Contact	Any instance where there is no contact with another vehicle, object, or pedestrian (e.g., tire blowout).	n/a

Using the crash narrative, crash type, and other data elements (e.g., contributing factors), data analysts also indicated if the crash could have been prevented or mitigated by the OBSS. More specifically, FCW, ACC, and CMBS were expected to reduce rear-end collisions in which the truck is striking another vehicle (and, to a lesser extent, head-on collisions); LDW was expected to reduce single-vehicle roadway departures, SDLDs, and opposite direction lane departures (and, to a lesser extent, head-on collisions); and RSC was expected to reduce rollover crashes involving combination trucks. However, even during these specified OBSS crash types there were situations in which the OBSS would not be effective. For example, FCW would not provide benefit in a situation where a vehicle encroached in the truck's lane; thereby causing the truck driver to make an avoidance maneuver that resulted in the truck rear-ending another vehicle. Table 7 includes a list of situations where the OBSS was assessed as being ineffective (per the literature review of these OBSSs). Data analysts did not code the crash as an OBSS-related crash (i.e., FCW crash) if any of these situations or circumstances in Table 7 were present.

Table 7. Exclusion Criteria for Each OBSS

OBSS	Situation Where the OBSS Would Not Be Effective
LDW	• Not effective when the driver makes an avoidance maneuver that resulted in the truck running off the road or sideswiping another vehicle or object. • Not effective when the driver uses his/her turn signal. • Not effective when heavy snow or other debris is covering lane markings. • Not effective on roads without any lane markings. • Not effective when the driver is incapacitated.
RSC	• Not effective in bobtails (i.e., tractor only). • Not effective when the driver is incapacitated. • Not effective when the truck is on unpaved road. • Not effective when the truck strikes (or is struck by) another vehicle or object that leads to a rollover or jackknife. • Not effective at low speeds (~15 miles per hour [mi/h] or 24.1 kilometers per hour [ki/h]). • Not effective if rollover was due to non-speed related reasons (e.g., driving into a ditch, tripped rollover).
FCW	• Not effective when the driver makes an avoidance maneuver that resulted in the truck striking another vehicle from behind. • Not effective when the truck is traveling less than 30 mi/h or 48.2 ki/h (unless the truck is equipped with a CMBS or ACC). • Not effective when the target was stationary when entered the range of radar. • Not effective when the driver is incapacitated.

Reliability was checked on approximately 30 percent of the data analysts' responses with respect to the crash type and OBSS-related designation in each crash file. The data analysts' coding was compared to a gold standard (i.e., a senior member of the research team). Inter-rater reliability on the crash type and OBSS-related designation was 96.4 percent and 99.7 percent, respectively.

2.1.2 Focus Groups

Although the primary evaluation in the current study relates to the safety efficacy of each OBSS, qualitative information on the acceptance and usage of these OBSSs by driver and safety management personnel was also assessed via focus groups. It was anticipated that information from motor carriers about the effectiveness of these systems in improving safety, in addition to drivers and safety managers' opinions and perceptions, will be valuable in advancing their further use in the trucking industry; thereby reducing the frequency and severity of vehicle crashes and their associated fatalities and injuries. The current study did not require Office of Management and Budget (OMB) approval due to the Intelligent Transportation Systems Joint Program Office Commercial Vehicle Operations exemption.

2.1.2.1 Focus-Group Recruitment

Current drivers and safety managers employed at the participating carriers were eligible to participate in the questionnaire and focus group research. Carriers were selected based on their willingness to participate in the focus groups and the presence of one of the three OBSSs. There were no exclusion criteria based on sex, health, status, or ethnicity; however, all participants had to be eligible for employment in the United States to participate. All drivers were at least 21 years old (since drivers must be 21 years old to possess a Class-A Commercial Driver's License) and have driving experience with the OBSS in question (i.e., drivers in the focus groups must have experienced an event that activated the OBSS).

For the focus group recruitment, drivers and safety managers from participating carriers who volunteered their support were recruited. Participating carriers made an announcement to drivers and safety managers regarding the current study and requested that interested volunteers contact the research team. Interested participants were instructed to call a toll-free number and/or send an email to the project manager. Flyers were also posted around the terminal/office locations. The flyer described the current study and listed a toll-free number and email address to contact for participation requirements and information. Lastly, research personnel recruited participants while onsite at the participating carrier. Potential participants were informed that their participation was voluntary, they could terminate their participation at any point without prejudice or harm, and their participation did not affect their employment status.

After contacting a member of the research staff and being fully informed of the study procedures, risks, compensation, and pre-screening, participants gave their verbal consent to participate in the focus group. After verbal agreement, the participant was informed regarding the location and time of the focus group meeting.

2.1.2.2 Focus-Group Procedures

Upon arrival, research staff reviewed the Institutional Review Board-approved Informed Consent Form with the participant. If the participant agreed with the terms outlined in the Informed Consent Form, they were asked to sign the form to indicate their consent (no particpants in the current study declined to participate). After signing the Informed Consent Form, the focus group began. Topics addressed in the focus group included perceptions and opinions of each OBSS, including the following topics (each topic was specific to the OBSS in question):

- How has the LDW, RSC, or FCW changed your driving?
- What are the benefits of the LDW, RSC, or FCW?
- What are the disadvantages of the LDW, RSC, or FCW?
- What would you change about the LDW, RSC, or FCW?
- Did you receive any training in using the LDW, RSC, or FCW?

- Has the LDW, RSC, or FCW prevented any crashes?
- Has the LDW, RSC, or FCW reduced the severity of a crash?
- Would you recommend the LDW, RSC, or FCW to other drivers/safety managers?
- Does the cost of the LDW, RSC, or FCW justify its use (safety managers only)?
- Would you remove the LDW, RSC, or FCW if you were given the opportunity?
- Please give your overall opinion of the LDW, RSC, or FCW?

The questions noted above were framed in regard to the specific OBSS at the participating carrier. See Appendix F for the focus group questions and procedures completed by research personnel during the focus group. As indicated above, drivers and managers attended separate focus groups to facilitate open and frank discussion. At the conclusion of the focus group, participants completed a brief Demographic Questionnaire (see Appendix G for the Driver and Safety Manager Demographic Questionnaires). After the focus group was completed, compensation arrangements ($25.00 per hour) were made and the participants were thanked for their participation.

The purpose of the focus group was to have participants freely discuss issues relating to the topics of interest. This encourages other participants to respond and participate. It would have been difficult for this type of discussion to take place if the researcher had to ask participants to slow down while the researcher recorded their responses. As such, the focus groups were audio-recorded. The audio recording allowed the researcher to observe and direct the focus group as well as allow participants to freely discuss the topics of interest. The audio recordings were transcribed after the focus groups were completed.

2.2 RESEARCH DESIGN

The study design determined the overall structure of the research and guided data collection and analyses. The research design addressed several issues, including what data should be collected and how these data should be analyzed. The study design focused on the efficiency of the method and the potential bias inherent in each method. Several study designs were considered based on preliminary data collected from participating carriers. Based on the preliminary data collected, the retrospective cohort approach appeared to be the preferred method.

Study designs can be divided into two general categories: the experimental study, and the observational study (depending on how treatment/exposure is determined). The current study had no control over the installation of a particular OBSS in a truck (as this decision was made at the carrier level). Thus, the current study was an observational study due to the lack of control for exposure (i.e., truck equipped with an OBSS or not equipped with an OBSS). As such, the study followed an epidemiological approach.[44] The retrospective cohort approach was the chosen design in the current study. The general framework and the corresponding advantages and disadvantages of the retrospective cohort approach are discussed in the following section.

2.2.1 Retrospective Cohort Approach

As the preliminary data showed that OBSS-related crashes were rare events, there were two levels of exposure status in this design: trucks with an OBSS (yes), or trucks without an OBSS (no). The safety outcomes were measured by whether the truck experienced a crash (case) or did not experience a crash (control). Thus, the safety benefits of each OBSS were evaluated by comparing the crash risk between the two exposure groups (i.e., each OBSS was considered to improve safety if the trucks equipped with an OBSS had a lower risk of OBSS-related crashes than trucks not equipped with an OBSS).

Two classical epidemiological methods were considered in the current study: case-control and cohort methods. The primary difference between these two methods is the direction of study. In the cohort study, the OBSS status of each truck is determined first (i.e., truck equipped with an OBSS, and truck not equipped with an OBSS). Subsequently, the safety outcomes in each truck are determined. In the case-control method, crashes involving a truck equipped with an OBSS are identified first. Subsequently, a group of trucks without crashes is selected as a control and the status (yes/no) of their OBSS is determined.

The cohort study has several advantages over the case-control study. The cohort study is less prone to bias compared to the case-control approach and is considered the gold standard in observational studies (such as the current study).[(45)] The case-control method is more likely to be biased. This bias is caused by improper control selection; however, this approach can be cost-effective for rare safety events (such as crashes). As it was possible to collect the OBSS status in all trucks in the current study, the cohort study was preferred. Figure 2 illustrates a schematic plot of the retrospective cohort method used in the current study.

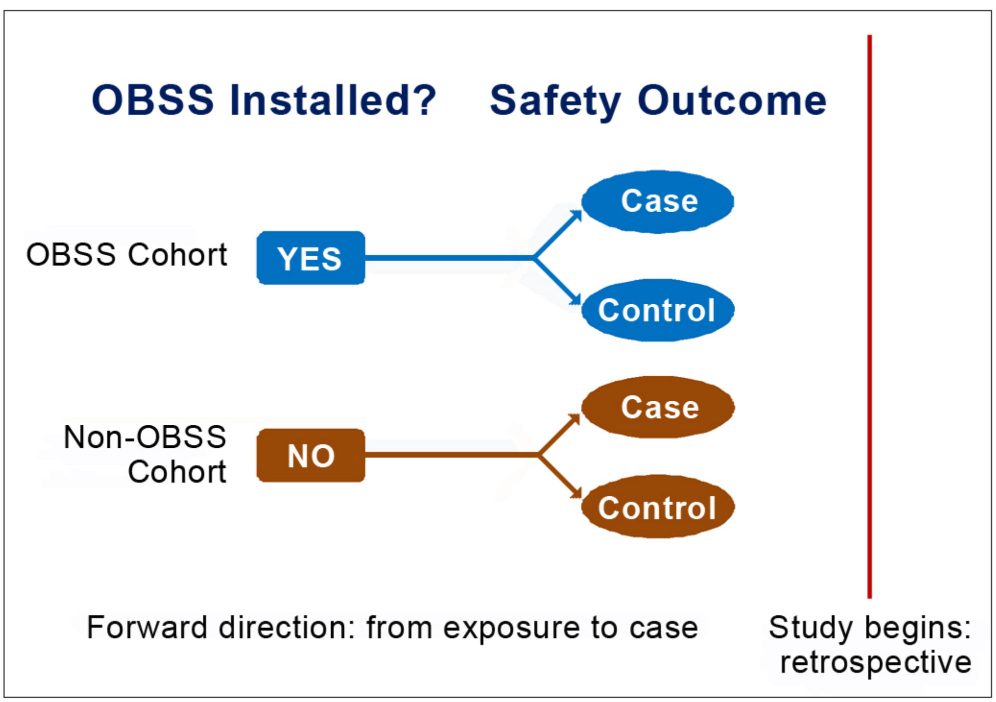

Figure 2. Diagram. Schematic of the Retrospective Cohort Design Used in the Current Study.

Since the current study was based on previous data, the overall study design was analogous to the classic retrospective cohort study. The retrospective cohort method is widely used to investigate occupational diseases in epidemiological research. The current study consisted of two major steps. In the first step, exposure information was collected. This included the collection of data to ascertain if a truck was equipped with OBSS and, if so, the determination of when the OBSS was installed in the truck. This data (i.e., date the OBSS was installed) was used to correctly apportion the crashes and miles for trucks where the OBSSs was installed mid-year during the period of performance (i.e., between 2007 and 2010). As shown in Table 13, two cohorts were formed based on OBSS status (i.e., an OBSS cohort and a Non-OBSS cohort). In the second step, the safety outcomes in each cohort were determined. The number of crashes by type for each truck was recorded as well as the mileage traveled in the study period. The specific crash types included:

- LDW systems were expected to reduce single vehicle roadway departures, same direction lane departures, and opposite direction lane departures (and, to a lesser extent, head-on crashes).
- RSC systems were expected to reduce rollover crashes.
- FCW systems were expected to reduce rear-end collisions in which the truck is striking another vehicle (and, to a lesser extent, head-on crashes).

The outputs in the retrospective cohort study are illustrated in Table 8. The characters “N0” and “N1” represent the number of crashes for trucks in the OBSS cohort and trucks in the non-OBSS cohort, respectively. The characters “E0” and “E1” represent the total mileage, as measured in MVMT, in the OBSS cohort and non-OBSS cohort, respectively.

Table 8. Outputs in the Retrospective Cohort Study

Variable	OBSS	Non-OBSS
Crashes	N0	N1
Exposure (Mileage)	E0	E1
Crash Rate	N0/E0	N1/E1

The individual truck mileage information provided an opportunity to evaluate the crash likelihood given the truck’s exposure. The OBSS-related crash rate was the primary measure of crash risk and was defined below in Figure 3.

$$Crash\ Rate|OBSS = \frac{N0}{E0}$$

Figure 3. Equation. OBSS-Related Crash Rate.

The OBSS-related crash rate was calculated by OBSS status. The safety impacts of a specific OBSS were evaluated by comparing the OBSS-related crash rate between the two cohorts (i.e., OBSS and non-OBSS). Two risk measures, the crash rate difference and the crash rate ratio were used in the current report as shown in Figure 4:

$$Crash\ Rate\ Difference = Crash\ Rate|(Non\text{-}OBSS) - Crash\ Rate|(OBSS) = \frac{N1}{E1} - \frac{N0}{E1}$$

$$Crash\ Rate\ Ratio = \frac{OBSS - Related\ Crash\ Rate|(Non\text{-}OBSS)}{OBSS - Related\ Crash\ Rate|(OBSS)} = \frac{\frac{N1}{E1}}{\frac{N0}{E0}}$$

Figure 4. Equations. Crash Rate Difference and Crash Rate Ratio.

The crash rate difference indicated the magnitude of the absolute change in OBSS-related crash risk "attributable" to the specific OBSS. A neutral value of risk difference of "0" suggests that the OBSS did not reduce the OBSS-related crash risk, and a risk difference value greater than "0" indicates that the specific OBSS reduced the OBSS-related crash risk. The risk difference was also used in the BCA.

The rate ratio is a ratio of the OBSS-related crash rate in the non-OBSS cohort versus the OBSS-related crash rate for the OBSS cohort. A neutral value is "1" (i.e., the OBSS has no safety benefit). A rate ratio value greater than "1" indicates that the OBSS improves safety. The statistical inference for rate ratio can be regression analysis, as described below.

2.2.1.1 Regression Model-Based Analysis

The formal statistical analysis to assess the safety benefit of each OBSS used a generalized linear model.(1) Specifically, the count based on the Poisson regression model was adopted to model the number of crashes with an adjustment to exposure (MVMT). This model (as shown in Figure 5) is the standard approach in modeling the number of traffic crashes.(45) Let Y_i be the number of crashes that occurred for truck "*i*". The model assumes Y_i follows a Poisson distribution as shown in Figure 5:

$$Y_i \sim \text{Poisson}(E_i \lambda_i)$$

Figure 5. Equation. Poisson Distribution.

Where E_i was exposure (i.e., miles traveled or MVMT) and $lambda_i$ was the expected crash rate as measured by the number of OBSS-related crashes per MVMT (the primary risk measure in the current study). A logarithm link function was used to relate the OBSS-related crash rate with risk factors as shown in Figure 6.

$$\log(\lambda_i) = X_i \beta$$

Figure 6. Equation. Logarithm Link Function.

Where X_i is the covariate matrix and *beta* is the vector of regression parameters. The OBSS status of the truck was treated as a categorical covariate. For example, the FCW covariate for truck "*i*" was defined in Figure 7.

$$X_{FCW,i} = \begin{cases} With\ FCW \\ Without\ FCW \end{cases}$$

Figure 7. Equation. FCW Covariate for Truck *"i"*.

The regression coefficient corresponding to X_{FCW} directly reflects the safety impact of FCW on the FCW-related crash risk. The significance of the parameter indicated whether FCW had a significant impact on the FCW-related crash rate. Furthermore, the contrast between the two levels of X_{FCW} was used to estimate the crash rate reduction (CRR) between the non-FCW and FCW cohorts as well as the confidence intervals in the CRR.

The regression model approach allowed multiple covariates to be included. In this situation, the inference of the regression coefficient reflected the impacts of the specific OBSS on OBSS-related crash rate conditioning on other factors in the same model.(45) The modeling method also provided a way to control the confounding factors by including them in the same model. One common problem with the Poisson regression-based safety model is the overdispersion issue (i.e., the variance is greater than the mean). This is a direct violation of Poisson model assumption and the research team addressed this issue by using a general estimation equation (GEE) modeled implemented through an R-side random effect in statistical analysis software (SAS) to accommodate the overdispersed data, which is a common practice to handle the overdispersed count data (see SAS PRC GLIMMIX manual).

2.3 OBSS BCA

The current study attempted to quantify the costs and benefits associated with LDW, RSC, and FCW using a formal economic analysis approach.(46,47) Conceptually, two alternatives were formulated to assess the potential cost of each OBSS: Alternative Zero (No OBSS) and Alternative One (Install OBSS). However, the Alternative One analysis included calculations for FCW, FCW with ACC, and CMBS. In order to make a comparison between Alternative Zero and Alternative One, the following factors were identified in each OBSS:

- Technology deployment costs.
- Crash costs for the crashes preventable by the specific OBSS.
- Crash benefits as a reduction in the crash rate or expected crash reduction.
- Analysis period(s) and discount rate(s).
- Evaluation methodology.

The deployment of each OBSS was anticipated to increase the safety of all the road users, but to impact different sectors of society in different ways. To contemplate these impact costs, benefits that were inherent in each group (e.g., industry, society) were considered, and different BCAs were required. In the current study, two BCAs were conducted, including: a BCA focused on the costs and benefits in the carrier industry by implementing each OBSS, and a BCA that measured the societal benefits of each OBSS. Societal benefits and costs can differ from the carrier benefits and costs measured in the marketplace due to imperfections arising from: external economies or diseconomies where actions by one party impose benefits or costs on other groups that are not compensated in the market place, a monopoly power that distorts the relationship between marginal costs and market prices, and specific taxes or subsidies (see Circular A-94). The cost of crashes prevented by each OBSS varied depending on the viewpoint (society or the carrier). The costs reported in the recently published FMCSA reports on the benefits and costs of LDW, RSC, and FCW were used as the basis for the crash costs in the current study.(3,9,36) However, the societal costs of the crashes were based on the results from Zaloshnja and Miller(48) using the adjusted values of statistical life (VSL). The benefits were computed by assessing the safety outcomes in each OBSS (via the crash rate or the number of crashes per MVMT). The BCA also considered small carriers, which are typically not self-insured, resulting in lower initial out-of-pocket costs. All the BCAs used 2008 U.S. dollars.

2.3.1 Technology and Deployment Costs for the Carrier

The costs associated in implementing each OBSS included all non-recurring costs, such as the initial cost of the equipment, installation, and initial training, as well as all recurring and operational costs (e.g., maintenance and training). As part of the data collection process, the research team conducted interviews with participating carriers to identify the equipment and deployment costs of each OBSS. Motor carriers were asked how much they paid for the OBSS, if they were able to negotiate the price based on volume, and if they paid for the equipment up-front or financed the equipment. In addition, information was gathered on the of costs of training, installation and maintenance, the number of hours for training, the cost per hour, and the average number of drivers per truck. The responses from the participating carriers showed a wide range in the equipment prices for each OBSS that was not due solely to different manufacturers and/or add-ons, but also from negotiations between the participating carriers and the manufacturers. To compute the final cost of each OBSS, the research team used this carrier data as well as data from the corresponding OBSS vendors. To account for variability in price due to different manufacturers, accessories, and negotiations between participating carriers and vendors, three cost estimates were calculated for each type of equipment: low, average, and high.

In general, the installation and training costs of the OBSS were included in the purchase costs. To compute the cost of training, the trainer's time, the trainees' time (drivers), necessary equipment (e.g., truck), facilities, and any travel and travel-related expenses were included in the calculations. Although the trainer's time was assumed to be included in the original purchase costs of each OBSS, each participating carrier was responsible for the cost of training each driver (i.e., the driver's time). The driver's time was computed using the 50th percentile driver salary from the Bureau of Labor Statistics(49) job category 53-3032 ($17.92 per hour). In addition, it was recommended that 31 percent be added to this hourly rate to cover fringe benefits;(3,9,36) thereby resulting in a total cost of $23.50 per hour. As the estimated safety benefit of each OBSS was assessed on a per truck basis, the number of training hours per truck was computed as the total hours of training needed per driver was multiplied by the average number of trucks per driver. The average number of drivers per truck was assumed to be "1"; however, to incorporate the high attrition rate in the industry, it was assumed driver training would be needed on an annual basis. During the course of the current study, it was clear that training represented a small portion of all the costs due to the few training hours needed for each OBSS. Thus, when each OBSS reaches a higher market penetration rate, it is expected the specific OBSS training will be considered part of the normal driving training, thereby eliminating these costs.

The cost of the truck and the facilities for training purposes was dependent on the participating carrier. As OBSS training was expected to last 1–2 hours (if present), it was reasonable to assume that one truck and one classroom were needed (making this cost negligible). With respect to the maintenance costs, previous interviews from the participating carriers reported minimal maintenance costs (usually considered part of the normal operating expenses). Participating carriers rarely reported outgoing costs. Thus, the final calculation (as shown in Figure 8) to obtain the full cost of the installation and deployment of each OBSS per year was computed as:

$$COBSS_y = OBSS_y + I_y + T_y + M_y$$

Figure 8. Equation. Calculation for Total Cost and Deployment of Each OBSS.

Where $COBSS_y$ = is the total cost of installation and deployment for each OBSS system for year y; Y = the year of the analysis period 0, 1, 2…n; $OBSS_y$ = the cost of the OBSS for year y; I_y = the installation cost of the OBSS for year y; T_y = the training costs for year y; and M_y = the maintenance cost for year y (if any). The ability to pay for each OBSS was expected to vary among carriers; however, due to the relatively small cost of each OBSS, two options were considered: the OBSS was paid in full at year 1, and the OBSS was financed over a period of 3 years. An average interest rate that reflects motor carrier and banking industry practices was used in the second option.(3,9,36) Only the first option (i.e., pay in full when buying the equipment) was considered when calculating the societal costs.

2.3.2 Federal Tax Savings

Each OBSS was assumed to be part of the truck cab and subject to a special Federal tax savings. A tax rate of 35 percent was used in the calculation of Federal tax savings (C corporations and S Corporations). However, these tax savings are subject to property depreciation over time. The Internal Revenue Service (IRS) uses the modified accelerated cost recovery system (MACRS) to estimate property depreciation. The percentages established in the IRS(50) Circular 946 for 3-year depreciation were used to compute the depreciation in OBSS costs by Federal tax savings. More specifically, a 33.3 percent reduction in year 1, a 44.4 percent reduction in year 2, a 14.8 percent reduction in year 3, and a 7.4 percent reduction in year 4 were used to compute the new $COBSS_{yt}$ as shown in Figure 9.(51)

$$COBSS_{yt} = COBSS_y - P_{OBSS} \times MACRS\%_y \times TB_{MC}$$

Figure 9. Equation. Total Cost of Installation and Deployment of OBSS Including Tax Deduction.

Where $COBSS_{yt}$ = the total costs of the installation and deployment of each OBSS in year y including tax deductions; $COBSS_y$ = the total costs of the installation and deployment of each OBSS in year y; y = the year of the analysis period (0, 1, 2…n); P_{OBSS} = the price of each OBSS; $MACRS\ \%_y$ = the depreciation rate per recovery period for year y; and TB_{MC} = the Federal tax bracket of the carrier. This Federal tax savings was only applied to the carrier BCA as the savings in taxes are only a transfer of funds for one segment of society to the other; thus, these costs were not included in the societal BCA.

2.3.3 Estimating the Crash Avoidance Benefits With Each OBSS

The overall benefit of each OBSS was computed as the difference in the costs of the OBSS subtracted by the costs of the crashes that were prevented by each OBSS. The following Section describes the two major types of crash costs that were used in the BCAs: reduced carrier costs (i.e., benefits) resulting from the avoidance of crashes by using each OBSS, and reduced societal costs (i.e., benefits) resulting from the avoidance of crashes by using each OBSS. Two BCAs were performed to assess the societal benefits of each OBSS: one for the identical analysis period in the carrier BCA (5 years), and one at 20 years to assess the benefit of mandatory deployment.

2.3.3.1 Carrier Crash Avoidance Benefits

FMCSA published a series of research reports in 2009 that reported extensive crash cost data from multiple representatives in the trucking industry, including: motor carriers, insurance companies, legal firms, review of large truck crash statistics, and expert opinions.[3,9,36] The costs in these studies included property damage, labor (recruitment, training, testing, hiring, and orientation), workers' compensation (medical, disability, vocational rehabilitation), operational (cargo damage, cargo delivery delays, loading, unloading, towing, inventory, storage), legal (attorney fees, injury and fatality settlement), and environmental (fines and clean up) costs (in 2007 U.S. dollars). Crash costs can vary widely by type of operation, fleet size, geographic range of operation, vehicle configuration, and commodities hauled; however, the reported crash costs can be interpreted as an approximation of typical expected values. In the prior FMCSA studies, the average costs per crash that could be avoided by each OBSS were differentiated by the severity of the crash, such as property damage only (PDO), injury, and fatal. Due to the small sample of crashes in the current study, the average cost per crash was used for each OBSS in the current study.

These costs were computed as the weighted average in the different types of crashes that could be avoided by each OBSS. This weighted average was computed using the distribution of PDO, injury, and fatal crashes found in the current study. As will be shown below in the Results Section, the distribution of these crashes differs from those found in GES over the same calendar years (i.e., 2007, 2008, and 2009). Table 9 shows an example of the average crash costs across each severity level that can be avoided using the FCW (in 2007 U.S. dollars). The prices were updated using the gross domestic product (GDP) deflator from the Bureau of Economic Analysis.[51]

Table 9. Benefit Estimates Per Rear-End Crash Avoided With FCW by Severity in 2007 U.S. Dollars.

Cost Category	PDO Crash	Injury Crash	Fatal Crash
Labor and Workers' Compensation	N/A	$6,973	$27,891
Operational	$11,150	$11,150	$11,150
Environmental	$14,000	$14,000	$14,000
Property Damage	$27,500	$27,500	$27,500
Legal Settlement	N/A	$89,440	$775,680
Court Costs and Other Legal Fees	$70,000	$90,000	$200,000
Total	$122,650	$239,063	$1,056,221

Murray et al., 2009b

2.3.3.2 Societal Crash Avoidance Benefits

The societal benefits represent the monetary value of an avoided crash in a society, especially expenses that are not necessarily paid by the carrier, and thus, borne by society, such as medical-related costs, emergency response service, property damage, lost productivity, the monetized value of the pain, and the suffering and quality of life decrements the family experiences in a death or injury. These avoided crash benefits do not include mental health care costs for crash victims, roadside repair costs, cargo delays, earnings lost by family and friends caring for the injured, and the value of schoolwork lost.

Crash avoidance benefits were specified for different truck categories and each of the KABCO severity ratings shown in Table 10 (K = killed, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, O = no injury). The estimates of crash avoidance benefits differ as a function of the type of truck involved in the crash. Although the crash categories in Table 10 are the same as those used in Zaloshnja and Miller,[(48)] the benefits were recently updated by FMCSA to reflect the new VSL figures. The VSL, defined as the value of improvements in safety that result in a reduction of one expected fatality, measures the benefit in preventing a fatality by the 'willingness to pay' concept. The VSL was recently updated from $3 million[(52)] to $6,000,000.[(53)] Crash avoidance benefits in Table 10 were computed using the maximum abbreviated injury score (a detailed medical classification developed by physicians).[(53)] To rate the survival threat that injuries pose, a 4-percent return rate was used to compute the present value (PV) of the crash avoidance benefit. The benefits of avoided property damage were computed using data from the insurance service office, including payments for the insurance claim, aggregate payments to the insured vehicle, and damage inflicted on other vehicles in at-fault crashes and other properties.[(48)] Note that quality-adjusted life year (QALY) is a measure of disease burden, including the quality and the quantity of life lived. QALY is used in assessing the value of money in a medical intervention. The QALY was computed using a VSL of $6,000,000, and the median age was computed using the median age of the U.S. population in 2005.

Zaloshnja and Miller[(48)] reported what can be construed as crash avoidance benefits for several types of trucks, including: straight truck no trailers; straight truck with trailers; bobtail, truck-tractor 1 trailer; truck-tractor 2–3 trailers; unknown, medium heavy trucks; and all medium heavy trucks. The most common truck type in the current study was the truck-tractor one trailer. Thus, this truck type was used to compute the societal crash avoidance benefits of crashes. FMCSA is working on updating the societal crash avoidance benefits, but these crash avoidance benefits were not available during the current study.

Table 10. Societal Crash Avoidance Benefits Per Truck-Trailer Crash Category.

Maximum Injury Severity in Crash	Number of People	Medical	Emergency Services	Property Damage	Lost Productivity From Delays	Total Lost Productivity	QALYs Based on VSL $6 Million	Total Cost Per Crash
O—No injury	1	$1,212	$130	$7,032	$5,441	$7,437	$2,833	$18,643
C—Possible injury	2	$14,090	$498	$16,689	$11,378	$28,797	$87,636	$147,709
B—Non-incapacitating Injury	1	$17,142	$222	$13,897	$8,565	$81,927	$165,947	$279,135
A—Incapacitating Injury	2	$57,402	$552	$17,684	$10,319	$165,191	$532,100	$772,929
K—Killed	2	$88,085	$1,619	$42,633	$16,181	$1,299,952	$6,201,311	$7,633,600
U—Injury, severity unknown	1	$5,875	$211	$11,186	$7,626	$14,077	$10,977	$42,326
Unknown	1	$2,308	$212	$9,744	$6,584	$10,489	$9,708	$32,460

Source: FMCSA's Research Division via personal communication on November 3, 2009

As with the carrier BCA, an average cost per crash was used for each OBSS in the current study. This cost was computed as a weighted average of the different types of crashes that can be avoided by each type of OBSS using the study database.

2.3.4 Identify Crash Avoidance Benefits as a Reduction in the Crash Rate

In the BCA, the safety benefits of each OBSS were computed as the difference in the crash rate per MVMT between the Alternative Zero (No OBSS) and Alternative One (Install OBSS). As mileage is dependent on each carrier's operation, different levels of exposure were considered, including 60,000 miles, 80,000 miles, 100,000 miles, 120,000 miles, 140,000 miles, 160,000 miles, and 180,000 miles per year per truck. Although prior studies(3,9,36) did not consider exposure of less than 80,000 VMT, the current study included 60,000 VMT, as the FHWA Highway Statistics report shows 65,000 average VMT for tractor trailers in 2008.(54) The average number of miles driven per truck in the current study was 86,000 VMT (range = 500 to 250,000 VMT).

The average annual crash avoidance benefit of each OBSS was computed as the difference in the number of crashes prevented by each OBSS multiplied by the cost of each type of crash. This can be shown mathematically in Figure 10.

$$AACC = \sum_{i,j} (CR_{ji0} - CR_{ji1}) \times AVMT_{MC} \times CC_{ji}$$

Figure 10. Equation. Average Annual OBSS Crash Avoidance Benefit.

Where *AACC* = average annual crash avoidance benefit for each annual VMT; *j* = type of crash each OBSS is expected to avoid; *i* = severity of the crash (e.g., PDO, injury, and fatal); CR_{ji0} = crash rate per MVMT per crash type *j* and severity *i* for the Alternative Zero; CR_{ji1} = crash rate per MVMT per crash type *j* and severity *i* for the Alternative One; $AVMT_{MC}$ = average MVMT per truck; and $CC_{j,i}$ = crash cost for crash type *j* and severity *i*.

2.3.5 Identify Analysis Period and Discount Rate

As part of BCA, the analysis period and the discount rate for each of the alternatives were defined.

2.3.5.1 Analysis Period

According to the Office of Management and Budget,(47) the analysis period "should cover a period long enough to encompass all the important benefits and costs" (p. 15). The current BCA used a 5-year analysis period. Although the costs involved are relatively straightforward, the OBSS-related crash rate for any single year can differ; thus, the current BCA assumed the safety benefits of each OBSS remained constant over the analysis period. This analysis period represents a conservative approach as it assumes each OBSS did not have any residual value over the 5-year period. It was assumed that carriers would not sell the equipment at the end of the 5 years. In addition, it is reasonable to assume that some companies will use the equipment over a greater period than 5 years. Of course, given the rapid development of new technologies, it can also be assumed that some carriers will replace older OBSSs with new and updated versions that will shorten the analysis period (thereby reducing the benefits).

The BCA that assumed a mandatory deployment in 2012 assumes the benefits begin immediately after the equipment is installed in the trucks in the year 2012 and extend for a 20-year period (through the year 2031). This BCA includes the purchase of new equipment every 5 years with the exception of the last year. The MVMT and the fleets of interests in this analysis were extracted from the Federal Highway Administration (FHWA) statistics. In 2008, combination unit trucks traveled 143,507 MVMT and there were 2,215,856 registered combination unit trucks. These values correspond to an average of 64,764 VMT per truck. As with the carrier BCA, there was an assumption of one driver per truck and a turnover rate of 100 percent. Mileage and the number of trucks are assumed to have an annual growth of 2.5 percent.(55)

2.3.5.2 Discount Rate

The discount rate is the rate that discounts into present value (PV) the cost and benefits in any future year. The discount rate is used to compute the PV of future costs and benefits using the formula shown in Figure 11.(56)

$$PV = \frac{P_y}{(1 + r)^y}$$

Figure 11. Equation. Formula to Compute Present Value.

Where *PV* = the PV of the amount invested; P_y = the dollar value of the future amount in time *y;* *r* = the discount rate*;* and *y* = the year in which P_y is computed (0, 1, 2, … n). The greater the discount rate, the lower the PV in future costs and benefits. A real discount rate of 7 percent was used following OMB(46) recommendations. OMB(47) also recommends doing a sensitivity analysis to show the impact of discount rate variation (using 3 percent and 7 percent).

2.3.6 Calculate BCA Measures

This Section describes the BCA measures that were computed to compare the benefits and costs in implementing each OBSS, including net present value (NPV), benefit-cost ratio (BCR), and payback period.

2.3.6.1 NPV

The NPV is the current value of all projected net benefits minus the sum of all the projected costs. If the NPV is greater than zero then it can be assumed that equipping the truck with an OBSS is a good alternative. The NPV was calculated as shown in Figure 12:(47,57)

$$NPV = \sum_{y=1}^{Y} \frac{(Benefits_y - Cost_y)}{(1 + r)^y}$$

Figure 12. Equation. Calculation for the Net Present Value.

Where $Benefits_y$ = the expected benefits for the year *y* (Figure 13) was computed as:

$$Benefits_y = Crash\ Costs_{y1} - Crash\ Costs_{y0}$$

Figure 13. Equation. Expected Benefits for Year "*y*".

Crash Costs$_{y0}$ = the expected crash costs for the year *y* in Alternative Zero, and *Crash Costsy*$_{y1}$ = the expected crash costs for the year *y* in Alternative One.

Costs$_y$ = the expected costs for the year *y* was computed as shown in Figure 14.

$$COBSS_y = COBSS_{y0} - COBSS_{y1}$$

Figure 14. Equation. Expected OBSS Costs for Year "*y*".

Where $COBSS_{y1}$ = the expected total costs of installing and operating the OBSS system in the year *y* in Alternative One; $COBSS_{y0}$ = the expected total costs of installing and operating the OBSS in the year *y* in Alternative Zero; *r* = the discount rate; and *y* = the year in which P_y *is* computed (0,1, … n).

2.3.6.2 BCR

The BCR was calculated as the NPV of benefits divided by the NPV of costs. If the BCR exceeds "1," then the benefits in installing the OBSS are higher than the costs incurred in buying, installing, and maintaining the OBSS. The BCR was calculated as shown in Figure 15.[57]

$$BCR = \frac{\sum_{y=1}^{n} \frac{Benefits_y}{(1+r)^y}}{\sum_{y=1}^{n} \frac{COBSS_y}{(1+r)^y}}$$

Figure 15. Equation. Benefit-Cost Ratio.

Where *BCR* = the BCR in implementing the OBSS over a period of analysis *n* and a rate of return *r*; $Benefits_y$ = the benefits in implementing the OBSS in year *y*; $COBSS_y$ = the costs in implementing the OBSS in the year *y; r = the discount rate*; and *n* = the number of years for the analysis period.

2.3.6.3 Payback Period

The payback period is defined as the length of time required to recover the cost in the investment (i.e., How long will it take for the cost of the OBSS to pay for itself?). All things being equal, the better investment has a shorter payback period. The payback period was expressed as the year or month in which the sum of benefits first exceeds the sum of the costs expressed in current dollars. The mathematical formula for the payback period is shown in Figure 16.[3,9,36]

$$Payback\ Period = \frac{System\ Cost}{Annual\ Cash\ Inflow}$$

Figure 16. Equation. Formula to Calculate Payback Period.

For each OBSS, the measures described above were computed to serve as a tool for the selection between the Alternative Zero and the Alternative One.

2.3.7 Sensitivity Analysis

Lastly, a sensitivity analysis was conducted by varying some of the assumptions in the formulas above (e.g., cost elements and areas with the greatest uncertainty). The sensitivity analysis for crash costs included small carriers, which are usually not self-insured and have lower initial out-of-pocket costs.

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3. RESULTS

Section 3 outlines the results from the data collected by the research team.

3.1 OVERVIEW OF CARRIER DATA

Sixteen carriers provided data for this study. Unfortunately, missing data from two of the carriers resulted in unusable data that precluded their inclusion in the analyses. Thus, 14 carriers provided all the required data (including data on crashes, non-crashes, and the Carrier Demographic and Information Sheet) to be included in the analyses.

3.1.1 Carrier Demographics

The carrier demographic data from the 14 participating carriers are presented in Table 11. Listed in Table 11 is a description of the carrier, including: number of power units, average length of haul, primary commodities, number of full-time employees, and drivers' average number of years of driving experience (carriers could provide more than one description for their fleet). As shown in Table 11, there was a good mix of small, medium, and large carriers.

Table 11. Participating Carriers' Demographic Information.

Carrier	Carrier Description	# of Power Units	Average Haul Length (in Miles)	Primary Commodities	# of Fulltime Employees	Average Driving Exp
Carrier A	For hire: truckload	1,001 or more	500 or more	BM, HM, FP, MO	1,001–5,000	NA
Carrier B	For hire: truckload	51–100	1–50	DOD	101–500	15 yrs
Carrier C	For hire: tanker Private: tanker	101–500	201–499	FFP	101–500	23 yrs
Carrier D	For hire: truckload	1,001 or more	201–499	GFT, BM, PF, RPP, FP, FFP, HG, RS	1,001–5,000	7 yrs
Carrier E	For hire: truckload	1,001 or more	500 or more	GFT, BM, PF, HM, FFP, RS	1,001–5,000	6 mo
Carrier F	For hire: truckload For hire: tanker	11–50	51–100	RPP and B	21–100	15 yrs
Carrier G	For hire: less-than-truckload	1,001 or more	500 or more	GFLTL	5,001 or more	20 yrs
Carrier H	For hire: truckload For hire: less-than-truckload Private: truckload Private: tanker Owner-operator	101–500	500 or more	Explosives and radioactive materials	101–500	10 yrs
Carrier I	For hire: truckload For hire: regional Owner-operator	1,001 or more	201–499	GFT, BM, HC, PF, APV, FP, FFP	5,001 or more	3.93 yrs
Carrier K	For hire: truckload For hire: regional For hire: tanker Owner-operator	1,001 or more	500 or more	GFT, HC, APV, RS, RaPP	5,001 or more	6 yrs
Carrier L	For hire: truckload For hire: regional For hire: tanker Owner-operator	1,001 or more	500 or more	GFT, GFLTL, BM, HC, PF, HM, FP, FFP, RS	5,001 or more	4 yrs
Carrier M	For hire: truckload For hire: less-than-truckload For hire: regional	101–500	201–499	GFT, GFLTL, PF, Other	101–500	8 yrs
Carrier N	For hire: less-than-truckload	1,001 or more	500 or more	GFLTL	5,001 or more	8.87 yrs
Carrier Q	For hire: truckload Private: truckload	51–100	500 or more	GFT, HG, RS	21–100	4.42 yrs

Primary Commodities Key: DOD = Department of Defense, GFT = General Freight Truckload, GFLTL = General Freight Less-than-Truckload, BM = Building Materials, HC = Hazardous Chemicals, PF = Processed Foods, HM = Heavy Machinery, RPP = Refined Petroleum Products, APV = Automotive Parts or Vehicles, FP = Forest Products, FFP = Farm Fresh Products, HG = Household Goods, RS = Retail Store—grocery delivery, RaPP = Raw Petroleum Products, B = Bulk – dump truck, P = Parcels, MO = Mine Ores

3.1.2 Carrier Safety Management Techniques and OBSSs

Table 12 lists the safety management techniques and OBSSs employed at each carrier. Listed in this table are the number of carriers that had an LDW system, RSC system, and/or FCW system, specific safety management techniques, other OBSSs, and safety evaluation areas (SEA). SafeStat uses available Federal motor carrier safety data to measure the relative safety status of motor carriers in four SEAs. As shown in Table 12, five carriers had an FCW in a portion of their fleet; of these, one had only FCW, one had only CMBS, one had FCW and ACC, and two had FCW, ACC, and CMBS. ACC systems include the functions of FCW systems; however, they also automatically maintain a minimum following interval to a lead vehicle in the same lane (when ACC is activated). A CMBS is a radar-based autonomous emergency braking system (i.e., when a collision is imminent the system applies a high level of braking force), as well as including the FCW and ACC functions. Separate analyses were conducted on each these FCW systems. Eight carriers had an RSC system in a portion of their fleet and five carriers had an LDW system in a portion of their fleet.

Table 12. Participating Carriers' Safety Management Techniques and OBSSs.

Carrier	FCW	RSC	LDW	Safety Management Techniques	Other OBSS	Accident SEA	Driver SEA	Vehicle SEA
Carrier A	FCW, ACC, CMBS	RSC	LDW	DFP, YTR, SI, FB, DDT, FCT, and SC	Qualcomm IVTM by Meritor	31.44	47.08	23.79
Carrier B	FCW, ACC	RSC	LDW	YTR, SI, and DDT	Sidetracker STD/7	9.25	14.74	8.68
Carrier C	None	No	No	YTR, SI, DDT, RA, and SC	Cadec Power Vue	44.18	10.75	26.84
Carrier D	FCW	RSC	LDW	DFP, YTR, SI, DDT, FCT, RA, HWP, and IsMyDrivingSafe observations	None	18.94	28.9	23.93
Carrier E	No	No	No	DFP, YTR, HMDP, SI, FB, DDT, FCT, SC, HWP, and Protective driving training	None	33.33	20.86	25.82
Carrier F	No	No	No	YTR, HMDP, SI, and RA	None	NA	36.02	15.72
Carrier G	No	RSC	No	DFP, SI, DDT, SC, and Required monthly safety meeting attendance	None	35.89	19.58	29.34
Carrier H	No	No	No	SC	None	45.9	38.02	15.72
Carrier I	No	RSC	No	DFP, YTR, HMDP, SI, FB, DDT, FCT, RA, SC, and HWP	None	29.01	34.05	34.06
Carrier K	No	RSC	No	DFP, YTR, HMDP, SI, FB, DDT, RA, SC, and HWP	Qualcomm MCP 200	NA	26.16	37.17
Carrier L	FCW, ACC, CMBS	RSC	LDW	DFP, YTR, SI, FB, DDT, FCT, SC, and HWP	None	85.83	57.88	31.19
Carrier M	No	No	No	YTR, HMDP, SI, FB, DDT, FCT, SC, and HWP	None	32.2	43.03	21.06
Carrier N	FCW, CMBS	RSC	LDW	YTR, SI, DDT, and HWP	None	19.3	21.42	35.79
Carrier Q	No	No	No	SI, DDT, RA, SC, and HWP	Qualcomm	NA	52.26	42.3

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

3.1.3 OBSS Penetration

Data were collected from 14 carriers including an initial total of 153,172 truck-years of on-the-road operation and 89,010 carrier-recorded (which is more than the number of USDOT-required to-be-reported) crashes. Truck-years do not reflect the number of mutually exclusive trucks over the 4 calendar years (as the same truck could be counted in each year), but rather the number of trucks over the 4 years of data collection. A portion of the data were excluded from the analyses due to data quality issues, including the following: 791 trucks without mileage information (860 crashes were associated with these trucks), 752 trucks whose annual mileage was less than 500 miles (32 crashes were associated with these trucks), and 5 trucks had more than 300,000 miles (6 crashes were associated with these trucks). As a result, 1,548 trucks were excluded from the analysis. The final dataset included data from 14 carriers with 151,624 truck-years that drove a total of 13 billion miles. The average mileage per truck per year was approximately 86,000 miles. Table 13 shows the number and percentage of truck-years with an FCW, RSC, and/or LDW. The percentage of trucks with an OBSS was calculated by dividing the number of trucks with the OBSS by the total number of trucks. For example, in 2007, 44 percent of the trucks had RSC or 21,598 trucks out of 48,735 trucks.

Table 13. Number and Percent of Truck-Years With Each OBSS.

Year	# With LDW	# Without LDW	% With LDW	# With RSC	# Without RSC	% With RSC	# With FCW	# Without FCW	% With FCW	TOTAL # Trucks
2007	2,590	46,145	5%	21,598	27,137	44%	1,732	47,003	4%	48,735
2008	4,045	44,078	8%	24,237	23,886	50%	2,916	45,207	6%	48,123
2009	4,788	40,326	11%	27,389	17,725	61%	3,966	41,148	9%	45,114
2010*	1,174	8,487	12%	1,174	8,487	12%	1,174	8,487	12%	9,652
TOTAL	12,597	139,027	8%	74,398	77,226	49%	9,788	141,836	6%	151,624

*Only one carrier had data in 2010

Table 14 shows the distribution of trucks with multiple OBSSs across each carrier (i.e., RSC, FCW, and/or LDW). The top row indicates the number of OBSSs installed on the trucks and the first column indicates the carrier. The numbers listed in each cell indicate truck-years.

Table 14. Number of Truck-Years With Multiple OBSSs Across Each Carrier.

Carrier	No OBSSs	One OBSS	Two OBSSs	Three OBSSs
A	–	–	217	3,645
B	–	–	–	63
C	587	–	–	–
D	2,814	118	–	–
E	2,361	–	–	–
F	98	–	–	–
G	2,455	991	–	–
H	824	–	.	–
I	18,721	19,648	–	–
K	13,144	37,164	–	–
L	902	3,755	3,205	4,539
M	645	–	–	–
N	34,267	–	–	1,174
Q	287	–	–	–

Table 15 shows the distribution of trucks by speed limiter setting across each carrier (i.e., RSC, FCW, and/or LDW). The numbers listed in the last column indicate truck-years.

Table 15. Number of Truck-Years by Speed Limiter Setting Across Each Carrier.

Carrier	Speed Limiter Setting (mi/h)	Truck-Years
A	65	3,862
B	65	63
C	60	587
D	No Setting	431
D	50	1
D	55	36
D	57	145
D	58	1
D	60	1,389
D	63	841
D	65	88
E	63	1,148
E	65	1,213
F	No Setting	98
G	62	3,446
H	No Setting	824
I	62	36,315
I	68	1,539
I	No Setting	515
K	63	50,308
L	65	12,401
M	65	645
N	62	35,441
Q	65	176
Q	70	111

3.1.4 Yearly Crash, Non-Crash, and Mileage Data

Table 16 shows the years of data, truck-years, MVMT, number of crashes, and the overall crash rate. The overall crash rate was defined as the number of crashes (i.e., total number of crashes) divided by MVMT. Each carrier had its own operational definition of what constituted a crash, which was broader than the reporting requirements of a USDOT-reportable crash. As shown in Table 16, the MVMT and overall crash rate varied substantially among carriers. Although the four carriers with the largest exposure (I, K, L, and N) had a similar overall crash rate (approximately seven crashes per MVMT), it was clear the crash rate varied substantially across carriers. The crash rate of 7 per MVMT was far higher than the large truck crash rate reported in the 2008 Traffic Safety Facts (1.36 crashes per MVMT). This does not reflect unsafe carriers, but rather a dataset that included a greater number and diversity of crashes than USDOT-reportable crashes.

Table 16. Years of Data, Truck-Years, MVMT, Number of Crashes, and Overall Crash Rate by Carrier.

Carrier	Years With Data	Truck - Years	MVMT	Number of Crashes	Overall Crash Rate
A	3	3,862	325	446	1.37
B	2	63	6	4	0.63
C	3	587	30	20	0.67
D	2	2,932	290	2,882	9.95
E	2	2,361	362	2,445	6.76
F	3	98	7	8	1.14
G	3	3,446	396	569	1.44
H	3	824	82	107	1.3
I	3	38,369	2,914	20,741	7.12
K	3	50,308	4,888	36,451	7.46
L	3	12,401	1,245	7,887	6.33
M	3	645	62	69	1.11
N	4	35,441	2,422	16,201	6.69
Q	3	287	36	282	7.93
TOTAL	N/A	151,624	13,065	88,112	Mean = 4.28

Table 17 shows the total number of crashes, OBSS-related crashes, truck-years, MVMT, overall crash rate, and the OBSS-related crash rate. The OBSS-related crash rate included the number of OBSS-related crashes divided by MVMT (i.e., the number of crash types for each OBSS noted in Table 6 subtracted by the number of those crashes that meet the exclusion criteria for each OBSS noted in Table 7 divided by MVMT). As shown in Table 17 and the overall crash rate in the LDW cohort was significantly less than the non-LDW cohort ($F_{(1,\ 152*10^3)} = 13.52$, $p = 0.0002$), the overall crash rate in the RSC cohort was significantly greater than the non-RSC cohort ($F_{(1,152*10^3)} = 145.2$, $p < 0.0001$), and the overall crash rate in the FCW cohort was significantly less than the non-FCW cohort ($F_{(1,152*10^3)} = 178.14$, $p < 0.0001$). As indicated above, the overall crash rate is difficult to interpret given that each participating carrier had their own operational definition of a crash. The OBSS-related crash rate was lower for trucks with an OBSS than for trucks without an OBSS. More specifically, the LDW cohort had a 48.4-percent lower LDW-related crash rate than the non-LDW cohort, the RSC cohort had a 37.5-percent lower RSC-related crash rate than the non-RSC cohort, and the FCW cohort had a 13.1-percent lower FCW-related crash rate than the non-FCW cohort. Note that these results do not take into account the existence of multiple OBSSs on some vehicles. The formal statistical analysis outlined under Section 3.2 used to quantify safety benefits with each OBSS follows a regression model discounting the confounding effects from other OBSSs in each OBSS-related crash type.

Table 17. Overall Crash Rate and OBSS-Related Crash Rate by OBSS Status.

Crash	LDW	No LDW	RSC	No RSC	FCW	No FCW
Total Crashes	5,932	82,180	49,157	38,955	3,629	84,483
OBSS-Related Crashes	115	2,289	281	384	65	1,129
Truck-Years	12,597	139,027	74,398	77,226	9,788	141,836
MVMT	1,156	11,910	7,059	6,007	814	12,252
Overall Crash Rate (MVMT)	5.1	6.9	7.0	6.5	4.5	6.9
OBSS-Related Crash Rate (MVMT)	0.099	0.192	0.040	0.064	0.080	0.092

Figure 17 shows the OBSS-related crash rate by OBSS status. The blue bars show the OBSS-related crash rate for each OBSS cohort and the black bars show the OBSS-related crash rate for the non-OBSS cohorts.

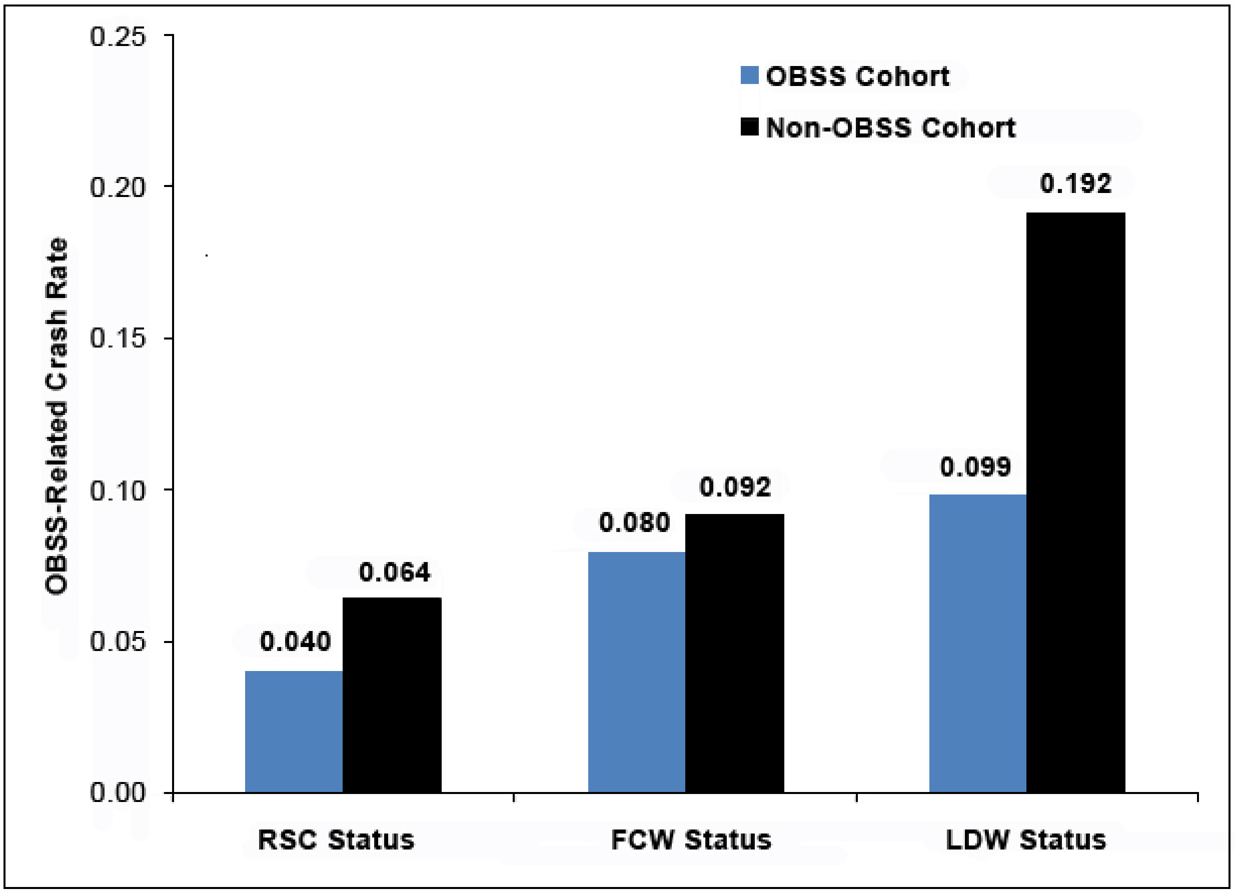

Figure 17. Bar Graph. OBSS-Related Crash Rate by OBSS Status

Table 18 shows the total number of crashes, LDW-related crashes, truck-years, MVMT, overall crash rate, and LDW-related crash rate by LDW cohort. Due to the low market penetration of LDW, the sample size was relatively small when stratified by carrier and LDW cohort. This contributed to the large variations in LDW-related crash rate by LDW cohort and fleet.

Table 18. Number of Truck-Years, Overall Crash Rate, LDW-Related Crash Rate, and MVMT by LDW Cohort

Carrier	LDW Cohort Truck-Years	LDW Cohort LDW - Related Crashes	LDW Cohort Overall Crashes	LDW Cohort MVMT	LDW Cohort LDW - Related Crash Rate	LDW Cohort Overall Crash Rate	Non-LDW Cohort Truck-Years	Non-LDW Cohort LDW - Related Crashes	Non-LDW Cohort Overall Crashes	Non-LDW Cohort MVMT	Non-LDW Cohort LDW - Related Crash Rate	Non-LDW Cohort Overall Crash Rate
A	3,645	21	442	318	0.0661	1.39	217	1	4	7	0.1405	0.562
B	63	0	4	6	0.0000	0.63	–	–	–	–	–	–
C	–	–	–	–	–	–	587	0	20	30	0.0000	0.673
D	74	0	64	8	0.0000	8.26	2,858	62	2,818	282	0.2199	9.997
E	–	–	–	–	–	–	2,361	32	2,445	362	0.0885	6.759
F	–	–	–	–	–	–	98	0	8	7	0.0000	1.136
G	–	–	–	–	–	–	3,446	28	569	396	0.0706	1.435
H	–	–	–	–	–	–	824	6	107	82	0.0728	1.299
I	–	–	–	–	–	–	38,369	1505	20,741	2,914	0.5165	7.118
K	–	–	–	–	–	–	50,308	373	36,451	4,888	0.0763	7.457
L	7,641	88	5,124	783	0.1123	6.54	4,760	59	2,763	462	0.1278	5.985
M	–	–	–	–	–	–	645	3	69	62	0.0483	1.110
N	1,174	6	298	41	0.1478	7.34	34,267	212	15,903	2,382	0.0890	6.677
Q	–	–	–	–	–	–	287	8	282	36	0.2250	7.932
TOTAL	12,597	115	5,932	1,156	0.099	5.1	139,027	2289	82,180	11,910	0.192	6.9

Figure 18 shows the LDW-related crash rate in the LDW cohort (blue bar) and non-LDW cohort (black bar). As shown in Table 18, the LDW-cohort in carrier N had very few truck-years compared to the non-LDW-cohort; thus, the LDW-related crash rate was highly variable.

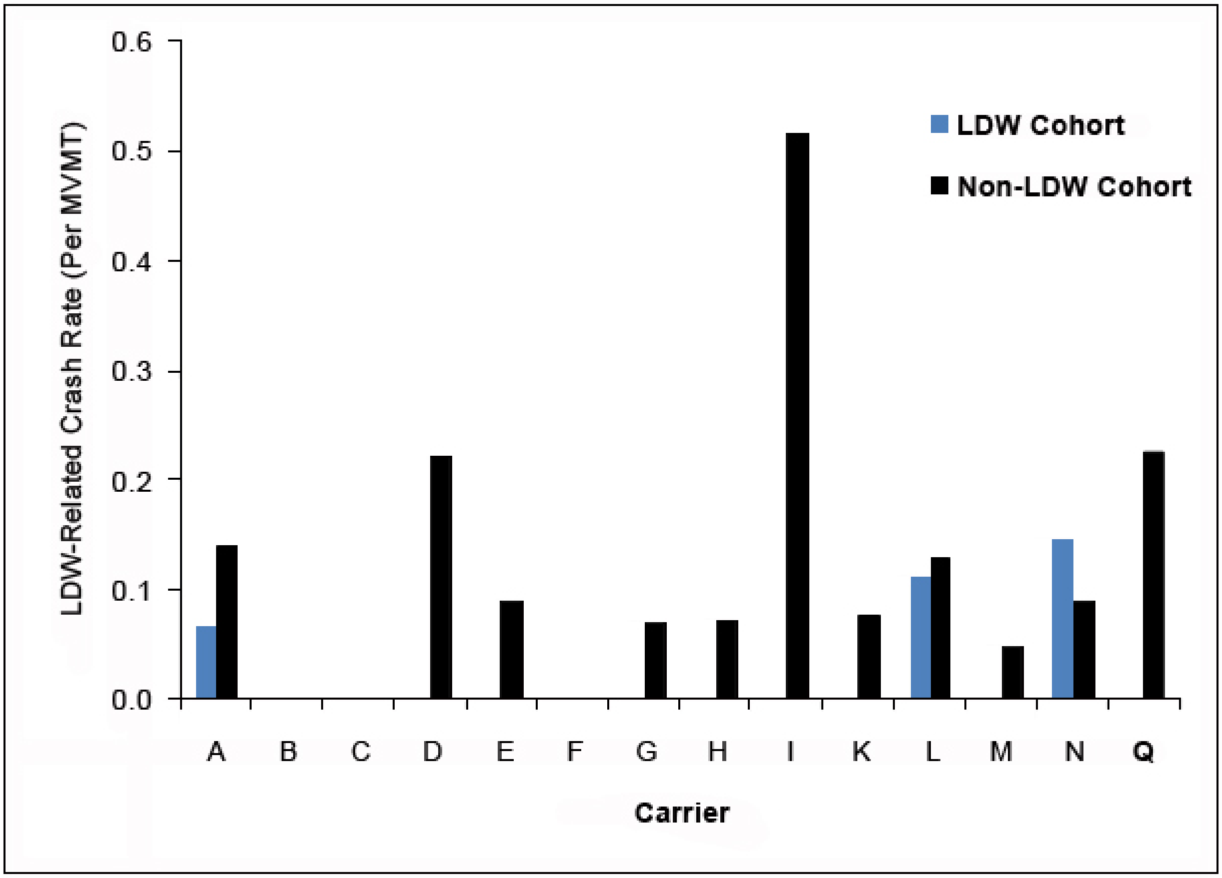

Figure 18. Chart. LDW-Related Crash Rate by LDW Cohort

Table 19 shows the total number of crashes, RSC-related crashes, truck-years, MVMT, overall crash rate, and RSC-related crash rate by RSC cohort.

Table 19. Number of Truck-Years, Overall Crash Rate, RSC-Related Crash Rate, and MVMT by RSC Cohort

Carrier	RSC Cohort Truck-Years	RSC Cohort RSC-Related Crashes	RSC Cohort Overall Crashes	RSC Cohort MVMT	RSC Cohort RSC-Related Crash Rate	RSC Cohort Overall Crash Rate	Non-RSC Cohort Truck-Years	Non-RSC Cohort RSC-Related Crashes	Non-RSC Cohort Overall Crashes	Non-RSC Cohort MVMT	Non-RSC Cohort RSC-Related Crash Rate	Non-RSC Cohort Overall Crash Rate
A	3,862	6	446	325	0.0185	1.37	–	–	–	–	–	–
B	63	0	4	6	0.0000	0.63	–	–	–	–	–	–
C	–	–	–	–	–	–	587	0	20	30	0	0.67
D	35	1	57	3	0.2995	17.07	2,897	20	2,825	286	0.070	9.87
E	–	–	–	–	–	–	2,361	8	2,445	362	0.022	6.76
F	–	–	–	–	–	–	98	1	8	7	0.142	1.14
G	991	1	6	99	0.0101	0.06	2,455	42	563	297	0.141	1.89
H	–	–	–	–	–	–	824	2	107	82	0.024	1.30
I	19,648	76	11,332	1,750	0.0434	6.48	18,721	108	9,409	1,165	0.093	8.08
K	37,164	139	29,474	3,656	0.0380	8.06	13,144	34	6,977	1,232	0.028	5.66
L	11,461	57	7,540	1,179	0.0483	6.39	940	7	347	66	0.106	5.26
M	–	–	–	–	–	–	645	1	69	62	0.016	1.11
N	1,174	1	298	41	0.0246	7.34	34,267	159	15,903	2,382	0.067	6.68
Q	–	–	–	–	–	–	287	2	282	36	0.056	7.93
TOTAL	74,398	281	49,157	7,059	0.04	7.0	77,226	384	38,955	6,007	0.064	6.5

Figure 19 shows the RSC-related crash rate in the RSC cohort (blue bar) and non-RSC cohort (black bar). As shown in Table 19, the RSC cohort in carrier D had very few truck-years and only one RSC-related crash; thus, the RSC-related crash rate was highly variable.

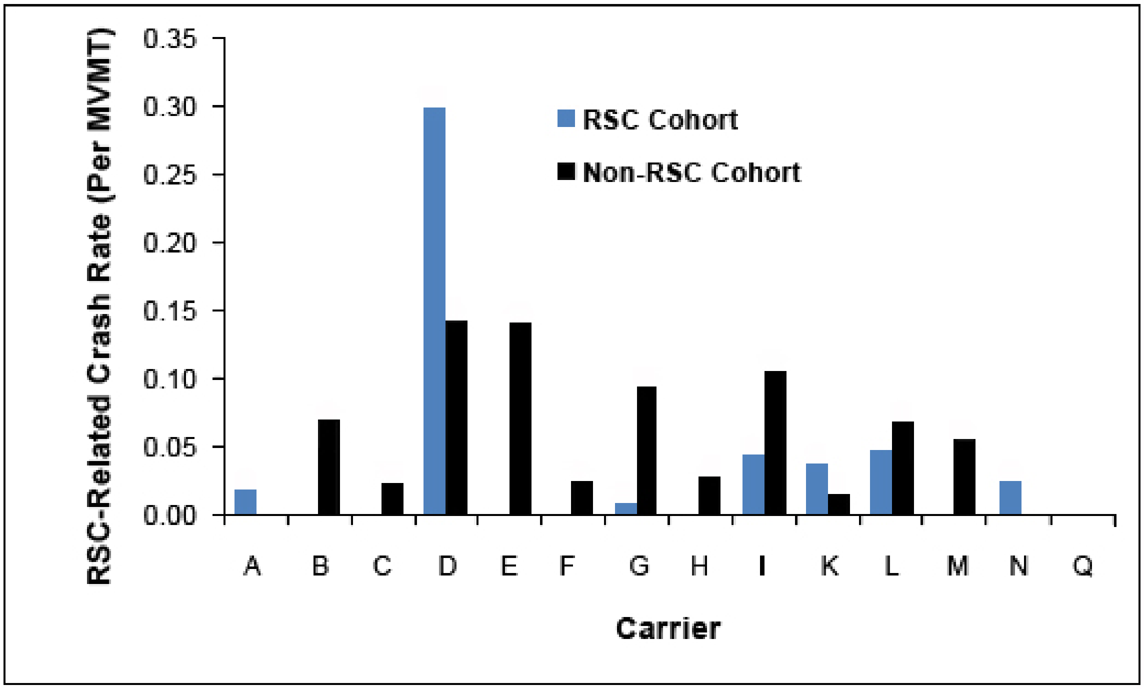

Figure 19. Chart. RSC-Related Crash Rate by RSC Cohort

Table 20 shows the total number of crashes, FCW-related crashes, truck-years, MVMT, overall crash rate, and FCW-related crash rate by FCW cohort. Due to the low market penetration of FCW, the sample size was relatively small when stratified by carrier and FCW cohort. This contributed to the large variations in the FCW-related crash rate by FCW cohort and fleet.

Table 20. Number of Truck-Years, Overall Crash Rate, FCW-Related Crash Rate, and MVMT by FCW Cohort

Carrier	FCW Cohort Truck-Years	FCW Cohort FCW-Related Crashes	FCW Cohort Overall Crashes	FCW Cohort MVMT	FCW Cohort FCW-Related Crash Rate	FCW Cohort Overall Crash Rate	Non-FCW Cohort Truck-Years	Non-FCW Cohort FCW-Related Crashes	Non-FCW Cohort Overall Crashes	Non-FCW Cohort MVMT	Non-FCW Cohort FCW-Related Crash Rate	Non-FCW Cohort Overall Crash Rate
A	3,862	24	446	325	0.0739	1.37	–	–	–	–	–	–
B	63	0	4	6	0.0000	0.63	–	–	–	–	–	–
C	–	–	–	–	–	–	587	0	20	30	0.0000	0.673
D	9	1	14	1	1.0530	14.74	2,923	23	2,868	289	0.0797	9.935
E	–	–	–	–	–	–	2,361	26	2,445	362	0.0719	6.759
F	–	–	–	–	–	–	98	1	8	7	0.1420	1.136
G	–	–	–	–	–	–	3,446	46	569	396	0.1160	1.435
H	–	–	–	–	–	–	824	7	107	82	0.0850	1.299
I	–	–	–	–	–	–	38,369	332	20,741	2,914	0.1139	7.118
K	–	–	–	–	–	–	50,308	368	36,451	4,888	0.0753	7.457
L	4,680	37	2,867	441	0.0838	6.49	7,721	102	5,020	804	0.1269	6.246
M	–	–	–	–	–	–	645	7	69	62	0.1126	1.110
N	1,174	3	298	41	0.0739	7.34	34,267	209	15,903	2,382	0.0877	6.677
Q	-	–	–	–	–	–	287	8	282	36	0.2250	7.932
TOTAL	9,788	65	3,629	814	0.08	4.5	141,836	1129	84,483	12,252	0.092	6.9

Figure 20 shows the FCW-related crash rate in the FCW cohort (blue bar) and non-FCW cohort (black bar). As shown in Table 20, the FCW cohort in carrier D had very few truck-years and only one FCW-related crash; thus, the FCW-related crash rate was highly variable.

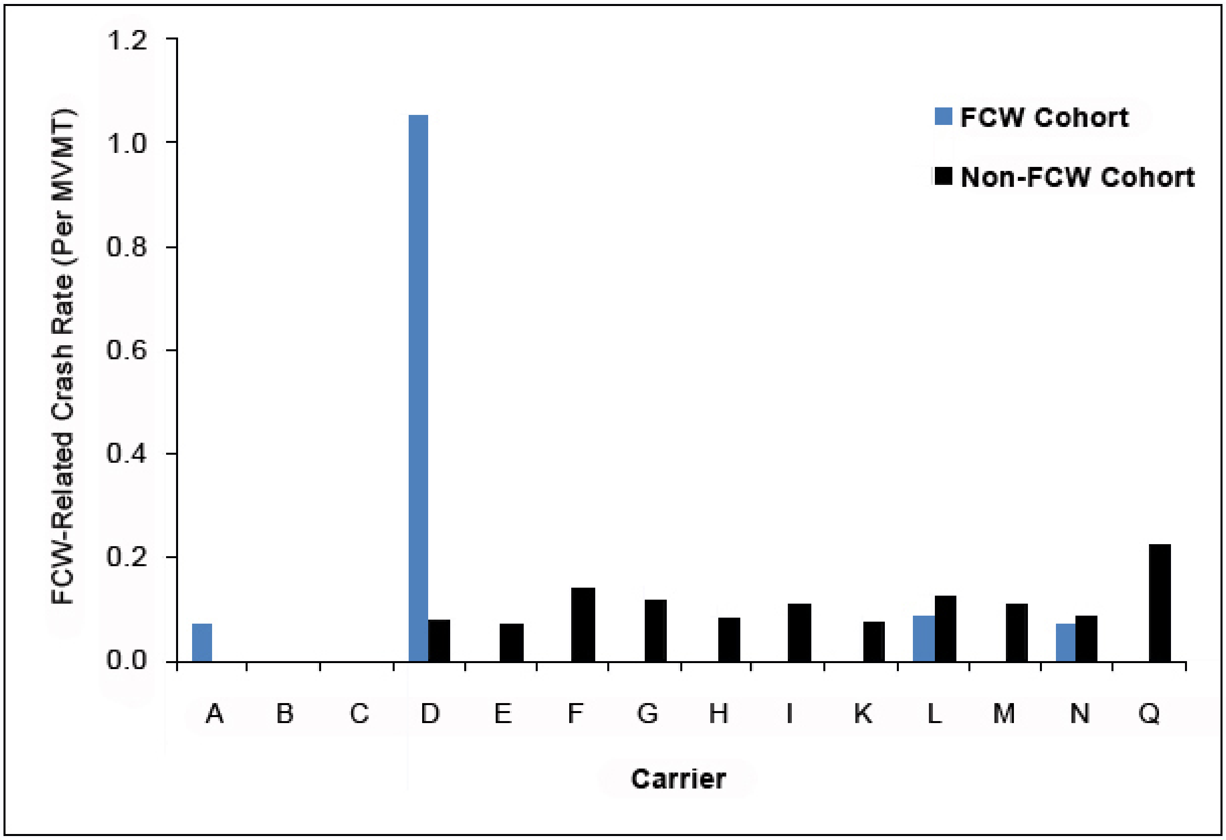

Figure 20. Bar Graph. FCW-Related Crash Rate by FCW Cohort.

3.1.4.1 Crash Severity

Table 21 shows the number and percentage of OBSS-related crashes by severity (i.e., injury, fatality, or PDO). As can be seen in Table 21, the percentage of fatal and injury OBSS-related crashes were higher than the overall percentage of crashes. For example, the percentage of fatal and injury FCW-related crashes was more than seven times greater than the overall percentage of crashes (1.68 and 22.3 percent versus 0.23 and 2.86 percent, respectively). These results indicate that, in general, OBSS-related crashes were more severe than the overall distribution of crashes. Table 21 clearly indicates that the crash datasets provided by carriers included mostly PDO crashes; however, the distribution of OBSS-related crashes also serves as a proxy manipulation check of data analysts' review of the OBSS-related crashes (as one would expect these crashes to be more severe than the overall distribution of crashes).

Table 21. Overall Crash Severity by OBSS

Crash Severity	LDW-Related Crashes (N)	LDW-Related Crashes (%)	RSC-Related Crashes (N)	RSC-Related Crashes (%)	FCW–Related Crashes (N)	FCW–Related Crashes (%)	Overall Crashes (N)	Overall Crashes (%)
Fatality	14	0.58%	4	0.60%	20	1.68%	207	0.23%
Injury	101	4.20%	116	17.44%	267	22.36%	2,519	2.86%
PDO	2,289	95.22%	545	81.96%	907	75.96%	85,386	96.91%
TOTAL	2,404	100%	665	100%	1,194	100%	88,112	100%

Table 22 shows the distribution of crashes in the current study and GES (calendar years 2007–09) by crash severity. The data for GES comes from a nationally representative sample of police-reported motor vehicle crashes of all types, from minor to fatal. The first number in each cell shows the percentage of crashes within each OBSS-related crash type, the second number in each cell (in parentheses) shows the percentage of OBSS-related crashes as a function of all crashes. The number of GES crashes were based on the crash types for each OBSS noted in Table 5 and used the exclusion criteria in Table 7 to filter GES crashes (where available). GES did not contain the level of detail regarding the circumstances of the crash as was available in the current study. The number of OBSS crash types reflects the number of crashes that correspond to the crash types of each OBSS noted in Table 6 (e.g., raw frequencies with no filtering). For example, the "FCW Crash Types in the Current Study" reflect the percentage of crashes for the FCW crash types noted in Table 6 (no exclusion criteria applied), whereas the "FCW-Related Crashes in Current Study" reflect the FCW-related crashes (exclusion criteria in Table 7 applied).

Most of the crashes in the current dataset were lower severity crashes that occurred in a parking lot (36.8 percent); only 9 percent of the crashes in the current dataset were USDOT-reportable crashes (only 5.3 percent of these USDOT-reportable crashes occurred in a parking lot). However, the current study had more LDW-related crashes than reported in GES, but these crashes were less severe than those found in GES. The non-filtered frequencies of OBSS crash types in the current study were more similar to GES than the OBSS-related crashes. Overall, the data in Table 22 suggest that there were fewer and less severe OBSS-related crashes in the current dataset than those found in GES.

Table 22. Distribution of OBSS-Related Crashes in the Current Study and GES by Severity

Crash Type	Percent of PDO Crashes (Percent of Total)	Percent of Injury Crashes (Percent of Total)	Percent of Fatal Crashes (Percent of Total)
GES LDW-Related Crashes (2007–09)	79.79% (3.16%)	19.80% (0.79%)	0.42% (0.02%)
LDW Crash Types in Current Study	91.92% (6.87%)	7.7% (0.58%)	0.38% (0.03%)
LDW-Related Crashes in Current Study	95.22% (2.6%)	4.20% (0.11%)	0.58% (0.02%)
GES RSC-Related Crashes (2007–09)	56.62% (0.47%)	40.42% (0.34%)	2.95% (0.02%)
RSC Crash Types in Current Study	84.61% (1.1%)	14.6% (0.19%)	0.79% (0.01%)
RSC-Related Crashes in Current Study	81.96% (0.62%)	17.44% (0.13%)	0.60% (0.005%)
GES FCW-Related Crashes (2007–09)	68.72% (3.18%)	29.75% (1.8%)	1.53% (0.07%)
FCW Crash Types in Current Study	78.9% (2.4%)	19.8% (0.6%)	1.3% (0.41%)
FCW-Related Crashes in Current Study	75.96% (1.03%)	22.36% (0.30%)	1.68% (0.02%)

3.2 SAFETY BENEFITS OF EACH OBSS

Formal statistical inference used the Poisson regression model described in Section 2. Three separate models were developed for the FCW, RSC, and LDW crash rates. Within each model, the statuses of all three OBSSs were included as covariates, thereby controlling the potential confounding effects caused by multiple OBSSs on the same vehicle.

$$Y_i \sim Poisson(E_i \lambda_i),$$
$$\text{Log}(\lambda_i) = X_{FCW,i}\,\beta_{FCW} + X_{RSC,i}\,\beta_{RSC} + X_{LDW,i}\,\beta_{LDW}$$

Figure 21. Equation. Model to Compute Crash Rates

Where lambda_i is the expected OBSS-related crash rate for truck *i* and $X_{FCW,i}$, $X_{LDW,i}$, *and* $X_{RSC,i}$ are indicator variables indicate the status of the three OBSS for truck *i*. Three models were fitted using the three OBSS-related crashes as response variable (Y_i). The regression covariates are the same for all three models ($X_{FCW,i}$, $X_{LDW,i}$, *and* $X_{RSC,i}$). Preliminary analyses indicated the presence of overdispersion (large chi-squared over degrees of freedom). The GEE approach was used to account for the overdispersion.

Table 23 shows the type III tests of fixed effects for each OBSS where all three OBSSs were used as covariates in the model. The first column in Table 23 shows the OBSS crash type, the second column shows the specific OBSS, the third and fourth columns show the numerator and denominator degrees of freedom (DF), respectively, the fifth column shows the *F* value, and the last column shows the *p* value. For example, Model 2 shows the fixed effect of each OBSS in reducing RSC-related crashes. Model 2 shows a significant reduction in the RSC-related crash rate for trucks equipped with RSC, but no significant impact on the RSC-related crash rate for trucks with LDW and FCW. The same relationship was found in Model 3 with LDW; however, the model for FCW (Model 1) was not significant. These results suggest that LDW was only effective in reducing LDW-related crashes and RSC was only effective in reducing RSC-related crashes. This is clear evidence supporting the safety effects of RSC and LDW.

Table 23. Type III Tests of Fixed Effects Modeling Output for OBSS-Related Crashes

Crash Type (Model)	OBSS	Numerator DF	Denominator DF	*F* value	Pr > *F*
LDW-Related Crashes (Model 3)	FCW	1	151,624	0.04	0.8487
LDW-Related Crashes (Model 3)	RSC	1	151,624	0.76	0.3836
LDW-Related Crashes (Model 3)	LDW	1	151,624	10.58	0.0011
RSC-Related Crashes (Model 2)	FCW	1	151,624	1.40	0.2367
RSC-Related Crashes (Model 2)	RSC	1	151,624	19.10	<.0001
RSC-Related Crashes (Model 2)	LDW	1	151,624	0.08	0.7821
FCW-Related Crashes (Model 1)	FCW	1	151,624	0.00	0.9909
FCW-Related Crashes (Model 1)	RSC	1	151,624	2.04	0.1535
FCW-Related Crashes (Model 1)	LDW	1	151,624	0.21	0.6460

Table 24 shows the CRR estimates for each OBSS. The first column in Table 24 shows the OBSS crash type, the second column shows the cohort comparison, the third column shows the contrast estimate, the fourth column shows the DF, the fifth column shows the *t* value, the sixth column shows the *p* value, the seventh column shows the CRR, and the last column shows the 95-percent confidence interval.

As shown in Table 24, there was a statistically significant difference between the non-LDW and LDW cohorts (CRR = 1.917, $p = 0.001$) and the non-RSC and RSC cohorts (CRR = 1.555, $p < 0.0001$). The non-LDW cohort had an LDW-related crash rate that was 1.917 times greater than the LDW cohort. The non-RSC cohort had an RSC-related crash rate that was 1.555 times greater than the RSC cohort. There was no significant difference in the CRR between the non-FCW and FCW cohorts (CRR = 0.997, $p = 0.991$).

The lack of statistically significant findings for FCW was most likely due to statistical power issues at the expected effectiveness levels. It was projected that there would potentially be borderline-sufficient statistical power to be able to detect FCW effectiveness in higher than expected range from historical studies but the results were statistically non-significant. There simply was not enough number of FCW-equipped vehicles in the dataset to be able to statistically detect safety benefits at the projected effectiveness levels.

While insufficiency of the FCW-relevant data in the dataset can explain the “statistical non-significance” of the observed safety benefits with FCW systems, the confounding effects of the driver being in the loop potentially affected the observed effectiveness levels. Previous FCW studies predicted a range of 3 percent to 21 percent effectiveness with the use of FCW systems but the high-end estimates were obtained assuming a perfect driver response (Fitch et al.,[(58)]) and marginal benefits were observed in naturalistic studies with the driver in the loop (Sayer et al,[(59)]). This study could be highlighting a similar effect, in statistically non-significant observations, whereby drivers' involvement in the loop may be lowering the in-service effectiveness of the deployed FCW systems.

Table 24. CRR Estimates for Each OBSS.

Crash Type (Model)	Cohort	Contrast Estimates	DF	*t* value	Pr > |t|	CRR	95% Confidence Interval
LDW-Related Crash Rate (Model 3)	Non-LDW vs. LDW	0.651	$152*10^3$	3.250	0.001	1.917	1.295–2.838
RSC-Related Crash Rate (Model 2)	Non-RSC vs. RSC	0.441	$152*10^3$	4.370	<0.0001	1.555	1.276–1.895
FCW-Related Crash Rate (Model 1)	Non-FCW vs. FCW	-0.003	$152*10^3$	-0.010	0.991	0.997	0.605–1.643

3.2.1 Safety Impact of Different FCW Systems

There were three different types of FCW systems, including FCW, ACC, and CMBS. It was hypothesized that these three devices had different impacts on the crash rate. Table 25 shows the number of FCW-related crashes, MVMT, and FCW-related crash rate by FCW type. As can be seen in Table 25, trucks with FCW and ACC had a 9.8 percent lower FCW-related crash rate than trucks without FCW, and trucks with CMBS had a 20.7 percent lower FCW-related crash rate than trucks without FCW.

Table 25. Crash Rate Estimates for Each FCW Type.

Variable	No FCW	FCW	ACC	CMBS
FCW-Related Crashes	1,129	37	8	20
Truck-Years	141,833	4,725	1,149	3,917
MVMT	12,251	446	96	272
FCW-Related Crash Rate	0.092	0.083	0.083	0.073

Of all the OBSSs, trucks with FCW had the lowest market penetration rate (especially ACC and CMBS). The number of crashes observed in these cohorts was relatively small. Table 26 shows the CRR estimates for each FCW type. The effects shown by the inference using the Poisson GEE model were ***not*** statistically significant (as illustrated in Table 26). It appears the CMBS exhibited the most promise in influencing FCW-related crash rate; however, there were too few crashes (i.e., limited power) to detect a significant difference (the current study was not designed to study this system).

Table 26. CRR Estimate for Each FCW Type

Cohort	Contrast Estimate	DF	*t* value	Pr > |t|	CRR	95% Confidence Interval
Non-FCW vs. CMBS	0.081	$152*10^3$	0.24	0.8107	1.08	0.56–2.11
Non-FCW vs. ACC	-0.048	$152*10^3$	-0.10	0.9191	0.95	0.38–2.46
Non-FCW vs. FCW	-0.038	$152*10^3$	-0.13	0.8940	0.96	0.55–1.68

3.3 BENEFIT COST ANALYSIS

3.3.1 LDW System

The following Section describes the BCA for LDW.

3.3.1.1 Technology and Deployment Costs

The questionnaire administered to motor carriers and vendors allowed an estimate of the average cost ($1,000), as well as an estimate of low ($800) and high ($1,200) cost estimates associated with LDW (as shown in Table 27). These costs assume that the LDW system was paid in full in year 1. Although this was the assumption in the societal BCA, it was also possible that carriers financed the technology (where the costs of LDW increase on a yearly basis). An average interest rate of 6.38 percent(3) and a 3-year loan period was used to compute the financed costs of the LDW system.

Table 27. Initial Cost and Cost Variation of Financing Over 3 Years for LDW

Option	Initial Cost	Year 1	Year 2	Year 3	Total Cost Financed
Low Cost Estimate	$800	$294	$294	$294	$881
Average Cost Estimate	$1,000	$367	$367	$367	$1,101
High Cost Estimate	$1,200	$441	$441	$441	$1,322

Figure 22 shows the LDW price variability for different discount rates with an initial price of $1,000. Although the average interest rate can vary, this variation in the average interest rate made little difference in the estimated cost of LDW considered in the current analysis (i.e., average, low, and high).

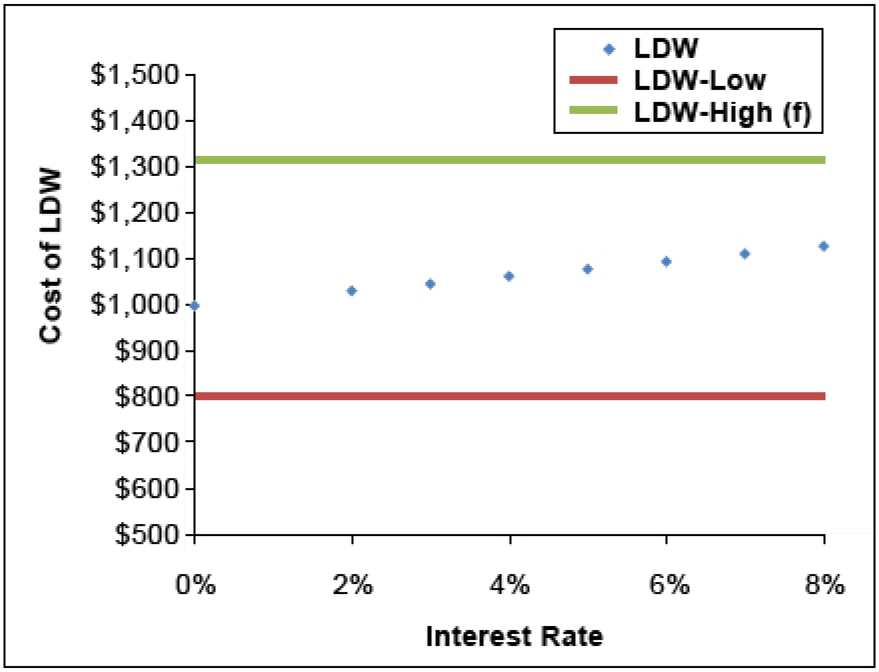

Figure 22. Chart. LDW Price Range Variability for Different Discount Rates for an Original Equipment Cost of $1,000 (f = Financed).

A tax rate of 35 percent was used to compute the Federal tax savings due to depreciation of LDW. The MACRS was used to estimate property depreciation following the instructions in IRS.[50] Table 28 shows the 5-year Federal tax savings due to the depreciation of LDW. As shown in Table 28, these costs were negative as it was a discount of the total cost of LDW. This depreciation was only calculated for the carrier BCA and not the societal BCA.

Table 28. Federal Tax Savings Due to the Depreciation of LDW.

Cost Estimate	Year 1	Year 2	Year 3	Year 4	Year 5
Low Cost Estimate	-$93.32	-$124.46	-$41.47	-$20.75	$0.00
Average Cost Estimate	-$116.66	-$155.58	-$51.84	-$25.94	$0.00
High Cost Estimate	-$139.99	-$186.69	-$62.20	-$31.12	$0.00

The time spent in LDW training varied from 15 minutes to 2 hours. An average training time of 1 hour was used in the BCAs. The cost of the driver's time was computed using the 50th percentile driver salary from the Bureau of Labor Statistics ($17.92 per hour).[49] This rate was adjusted upward by 31 percent to cover fringe benefits;[3,35] thereby resulting in a total hourly cost of $23.47. Given the high attrition rate in the trucking industry, it was assumed that driver training was conducted on an annual basis. Table 29 and Table 30 show the total cost of LDW deployment in the carrier and societal BCAs, respectively (where f = financed). The tables show that for an average estimated cost of $1,000 for LDW, the total costs of LDW deployment in the carrier BCA was $767.38 ($868.77 if financing) and $1,117.38 for LDW deployment in the societal BCA.

Table 29. Total Cost of LDW Deployment in the Carrier BCA.

Price	Option	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Low Cost Estimate	LDW	$730.15	-$100.98	-$17.99	$2.73	$23.48	$637.38
Low Cost Estimate	LDW(f)	$223.89	$192.76	$275.75	$2.73	$23.48	$718.60
Average Cost Estimate	LDW	$906.82	-$132.10	-$28.36	-$2.46	$23.48	$767.38
Average Cost Estimate	LDW(f)	$273.95	$235.03	$338.77	-$2.46	$23.48	$868.77
High Cost Estimate	LDW	$1,083.49	-$163.21	-$38.73	-$7.65	$23.48	$897.38
High Cost Estimate	LDW(f)	$324.08	$277.38	$401.86	-$7.65	$23.48	$1,019.15

Table 30. Total Cost of LDW Deployment in the Societal BCA.

Price	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Low Cost Estimate	$823.48	$23.48	$23.48	$23.48	$23.48	$917.38
Average Cost Estimate	$1,023.48	$23.48	$23.48	$23.48	$23.48	$1,117.38
High Cost Estimate	$1,223.48	$23.48	$23.48	$23.48	$23.48	$1,317.38

The NPV for LDW was computed using discount rates of 3 percent and 7 percent. Table 31 and Table 32 show the NPV for the total costs of LDW deployment in the carrier and societal BCAs, respectively (where f = financed).

Table 31. NPV for the Total Costs of LDW by Discount Rates in the Carrier BCA.

Price	Option	0% Discount Rate	3% Discount Rate	7% Discount Rate
Low	LDW	$1,092.38	$1,068.25	$1,037.61
Low	LDW(f)	$1,244.48	$1,169.65	$1,080.95
Average	LDW	$1,417.38	$1,388.50	$1,351.40
Average	LDW(f)	$1,620.19	$1,523.71	$1,409.20
High	LDW	$1,742.38	$1,708.74	$1,665.18
High	LDW(f)	$1,995.78	$1,877.66	$1,737.33

Table 32. NPV of the Total Costs of LDW by Discount Rates in the Societal BCA.

Price	0% Discount Rate	3% Discount Rate	7% Discount Rate
Low	$917.38	$884.21	$843.92
Average	$1,117.38	$1,078.38	$1,030.83
High	$1,317.38	$1,272.56	$1,217.75

Figure 23 shows the impact on the total cost of LDW with an increase in the number of drivers from 1 driver per truck to 1.5 and 2 drivers per truck, and turnover rates of 200 percent and 25 percent (with an average cost of $1,000 for LDW and discount rates of 0, 3, and 7 percent). The variability in these costs was not significant and was always less than the variability in equipment costs associated with LDW (i.e., low, average, and high). For example, with an LDW cost of $1,000 and a discount rate of 0 percent, the costs for 1, 1.5, and 2 drivers per truck were $767.38, $826.06, and $884.75, respectively. Similar costs were obtained with different discount rates and retention rates.

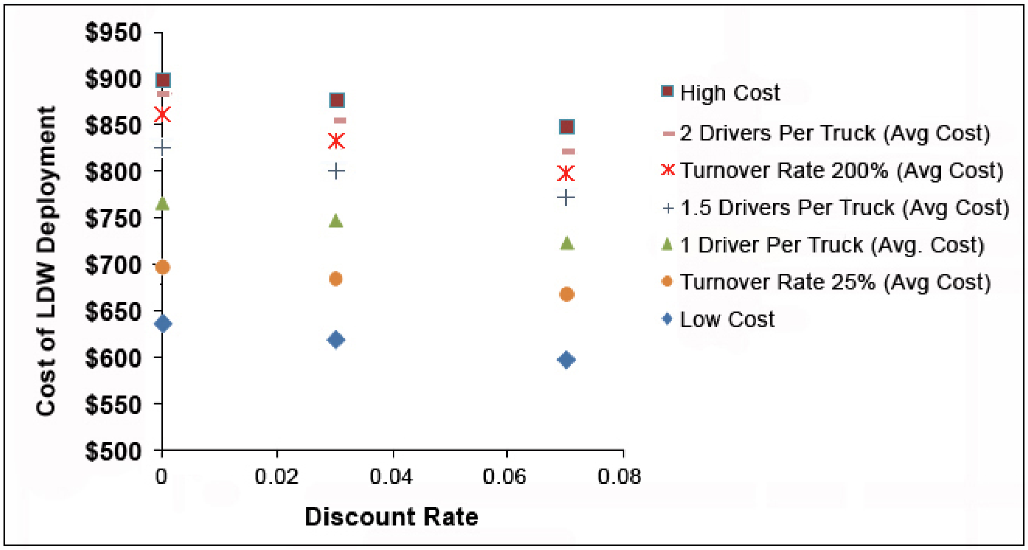

Figure 23. Line Graph. Influence of Salary, Discount Rates, and Turnover Rates on LDW Deployment Costs.

3.3.1.2 Crash Avoidance Benefits

The following Section describes the types of crash avoidance benefits that resulted from the carrier and societal BCAs.

Carrier Crash Avoidance Benefits: Table 33 shows that the carrier crash avoidance benefit estimates used in the current study were values taken from report by Houser et al.,[(3)] using the GDP deflator (based on 2008 U.S. dollars). These values assumed the carrier was self-insured or maintained a per-crash deductible that exceeded total crash costs. PDO crashes avoided were the least, with a total of $122,054 per avoided crash; injury crashes avoided were worth $331,035 to the carrier; and fatal crashes were worth $1,108,147 to the carrier. Labor and workers' compensation applied only when the truck driver involved in the crash was injured or killed. These values assumed there were 0.10 driver injuries per injury crash and 0.4 driver fatalities per fatal crash. To compute the average settlement benefit per injury and fatal rear-end crash avoided, it was assumed 1.3 injuries per injury crash, 1.1 injuries per fatal crash, and 1 fatality per fatal crash.[(3)]

To determine the average benefits for crashes involving large trucks that were avoided by LDW, the weighted average was computed using the severity distributions (PDO, injury, and fatal) that were avoided with the LDW in the current study database. As indicated in Table 21, this distribution of LDW-related crashes resulted in 95.22 percent PDO crashes, 4.2 percent injury crashes, and 0.58 percent fatal crashes. Thus, the resultant weighted average benefit per avoided LDW-related crash was $137,672.

Table 33. Benefit Estimates Per Lane Deviation Crash by Severity.

Severity	Type of Crash	Labor and Workers' Compensation	Operational	Environment	Property Damage	Legal Settlement	Court Costs and Other Legal Fees	Total Cost
PDO	SVRD Collision	N/A	$29,578	$35,759	$34,908	N/A	$40,868	$141,113
Injury	SVRD Collision	$64,116	$29,578	$35,759	$34,908	$134,863	$61,301	$360,526
Fatal	SVRD Collision	$64,116	$29,578	$35,759	$34,908	$942,000	$173,688	$1,280,049
PDO	SVRD Rollover	N/A	$29,246	$84,290	$57,044	N/A	$30,651	$201,230
Injury	SVRD Rollover	$71,241	$29,246	$84,290	$57,044	$188,247	$35,759	$465,826
Fatal	SVRD Rollover	$71,241	$29,246	$84,290	$57,044	$715,184	$112,386	$1,069,390
PDO	ODLD Head-on	N/A	$13,946	$24,521	$28,097	N/A	$40,868	$107,431
Injury	ODLD Head-on	$7,124	$13,946	$24,521	$28,097	$133,024	$45,976	$252,688
Fatal	ODLD Head-on	$21,372	$13,946	$24,521	$28,097	$867,212	$122,603	$1,077,750
PDO	SDLD Sideswipe	N/A	$13,946	$24,521	$28,097	N/A	$35,759	$102,322
Injury	SDLD Sideswipe	$14,249	$13,946	$24,521	$28,097	$11,239	$45,976	$138,026
Fatal	SDLD Sideswipe	$0	$13,946	$24,521	$28,097	$715,184	$122,603	$904,350
PDO	ODLD Sideswipe	N/A	$13,946	$24,521	$28,097	N/A	$35,759	$102,322
Injury	ODLD Sideswipe	$14,249	$13,946	$24,521	$28,097	$14,304	$45,976	$141,092
Fatal	ODLD Sideswipe	$0	$13,946	$24,521	$28,097	$726,423	$122,603	$915,589

SVRD = Single Vehicle Road Departure; SDLD = Same Direction Lane Deviation; ODLD = Opposite Direction Lane Deviation

Societal Crash Avoidance Benefits: Table 34 shows how the societal benefits were computed using the values provided by FMCSA. These values correspond to those reported in Zaloshnja and Miller,[48] but were modified with a VSL of $6 million and adjusted to 2008 U.S. dollars using the GDP deflator.

Crash avoidance benefits are specified for each of the KABCO severity ratings in Table 34. To compute the crash avoidance benefits in injury crashes, a weighted average was computed using category C (possible injury), category B (non-incapacitating injury), category A (incapacitating injury), and category U (injury severity unknown) that resulted in an average crash avoidance benefit of $334,888. The crash avoidance benefits for fatal crashes correspond with category K (killed), and for PDO crashes with category O (no injury), for total costs of $7,633,600 and $18,643, respectively. (Note that the PDO crash avoidance benefit to society of $18,643 is about 9–18 percent of the total PDO crash cost of $102,322 [from Table 33—PDO Sideswipe] to the carrier because the PDO crash avoidance benefit to society does not include avoided court and legal fees, operational, and environmental considerations.) To compute the average crash avoidance benefit per crash, the weighted average of the distribution of LDW-related crashes (property, injury and fatal) in the current study database was used. This resulted in an average benefit of $76,432 for an avoided LDW-related crash.

Table 34. Societal Crash Avoidance Benefits Per Truck-Trailer Crash Category.

Maximum Injury Severity in Crash	Number of People	Medical	Emergency Services	Property Damage	Lost Productivity From Delays	Total Lost Productivity	QALYs Based on VSL $6 Million	Total Cost Per Crash
O–No injury	*1.12*	$1,212	$130	$7,032	*$5,441*	$7,437	$2,833	$18,643
C–Possible inj	*1.53*	$14,090	$498	$16,689	*$11,378*	$28,797	$87,636	$147,709
B–Non-incap. Injury	*1.49*	$17,142	$222	$13,897	*$8,565*	$81,927	$165,947	$279,135
A–Incap. Injury	*1.57*	$57,402	$552	$17,684	*$10,319*	$165,191	$532,100	$772,929
K–Killed	*1.58*	$88,085	$1,619	$42,633	*$16,181*	$1,299,952	$6,201,311	$7,633,600
U–Inj., severity unknown	*1.19*	$5,875	$211	$11,186	*$7,626*	$14,077	$10,977	$42,326
Unknown	*1.49*	$2,308	$212	$9,744	*$6,584*	$10,489	$9,708	$32,460

Obtained From FMCSA's Research Division via Personal Communication on November 3, 2009

3.3.1.3 *Identify Crash Avoidance Benefits as a Reduction in the Crash Rate*

The crash rate was computed as the difference between the LDW-related crash rate in the non-LDW cohort (0.192 crashes per MVMT) and the LDW cohort (0.099 crashes per MVMT; difference = 0.093 crashes per MVMT). Table 35 shows the average carrier and societal savings in crash cost per truck per year with a 0-percent discount rate (as well as the 5-year total) for LDW. For example, the savings in the reduction of LDW-related crashes in carriers with LDW installed on a truck that travels an average of 100,000 miles per year was $1,267 per year ($6,335 per truck over the 5-year analysis period).

Table 35. Undiscounted Average Savings in the Reduction of LDW-Related Crashes With LDW

VMT	Per Year for Carriers	5-Year Total for Carriers	Per Year for Society	5-Year Total for Society
60,000	$760	$3,800	$425	$2,125
80,000	$1,014	$5,070	$567	$2,835
100,000	$1,267	$6,335	$709	$3,545
120,000	$1,521	$7,605	$850	$4,250
140,000	$1,774	$8,870	$992	$4,960
160,000	$2,027	$10,135	$1,134	$5,670
180,000	$2,281	$11,405	$1,275	$6,375

Table 36 shows the average carrier crash cost per truck with LDW in the 5-year analysis period with discount rates of 0 percent, 3 percent, and 7 percent.

Table 36. Discounted Average Carrier Savings Over 5 Years in the Reduction of LDW-Related Crashes With LDW.

VMT	0% Discount Rate	3% Discount Rate	7% Discount Rate
60,000	$3,801	$3,482	$3,117
80,000	$5,068	$4,642	$4,156
100,000	$6,335	$5,803	$5,195
120,000	$7,603	$6,964	$6,234
140,000	$8,870	$8,124	$7,273
160,000	$10,137	$9,285	$8,313
180,000	$11,404	$10,445	$9,352

Table 37 shows the average societal crash cost per truck with LDW in the 5-year analysis period with discount rates of 0 percent, 3 percent, and 7 percent.

Table 37. Discounted Average Societal Savings Over 5 Years in the Reduction of LDW-Related Crashes With LDW.

VMT	0% Discount Rate	3% Discount Rate	7% Discount Rate
60,000	$2,126	$1,947	$1,743
80,000	$2,834	$2,596	$2,324
100,000	$3,543	$3,245	$2,905
120,000	$4,252	$3,894	$3,487
140,000	$4,960	$4,543	$4,068
160,000	$5,669	$5,192	$4,649
180,000	$6,377	$5,841	$5,230

The following sections describe the measures in the BCA that were computed to compare the benefits and costs in implementing LDW, including: NPV of the different alternatives, BCR, and payback period. The BCR, NPV, and payback periods were computed for various scenarios, including: carrier and society; discount rates of 0, 3, and 7 percent; low, average, and high technology costs; with and without financing; and various VMTs (60,000 to 180,000 miles per year). In addition, several scenarios were calculated in the sensitivity analysis for a longer analysis period, mandatory deployment, high-value cargo, and small carriers.

3.3.1.4 Carrier BCA for LDW

Table 38 shows the carrier BCR, NPV, and payback periods for purchasing LDW at an average price of $1,000 by varying discount rates (without financing). The table shows that the benefits of installing LDW outweigh the costs in all scenarios (the BCR was greater than "1" and the NPV was positive).

Table 38. The Estimated Carrier BCR, NPV, and Payback Periods for Trucks With LDW at an Average Price (Without Financing)

VMT	BCR With 0% Discount	BCR With 3% Discount	BCR With 7% Discount	NPV With 0% Discount	NPV With 3% Discount	NPV With 7% Discount	Payback Period (Months)
60,000	4.95	4.65	4.31	$3,034	$2,734	$2,393	12
80,000	6.60	6.21	5.74	$4,301	$3,894	$3,432	9
100,000	8.26	7.76	7.18	$5,568	$5,055	$4,472	7
120,000	9.91	9.31	8.61	$6,835	$6,215	$5,511	6
140,000	11.56	10.86	10.05	$8,102	$7,376	$6,550	5
160,000	13.21	12.41	11.48	$9,369	$8,537	$7,589	5
180,000	14.86	13.96	12.92	$10,636	$9,697	$8,628	4

Figure 24 illustrates the impact on the BCR when varying the initial cost of the LDW and the discount rate. The dotted horizontal line in illustrates when the BCR was "1" (i.e., where the benefits in installing LDW equal the benefits accrued as a reduction in crash costs over the 5-year analysis period). All of the scenarios in Figure 24 had a BCR greater than "1."

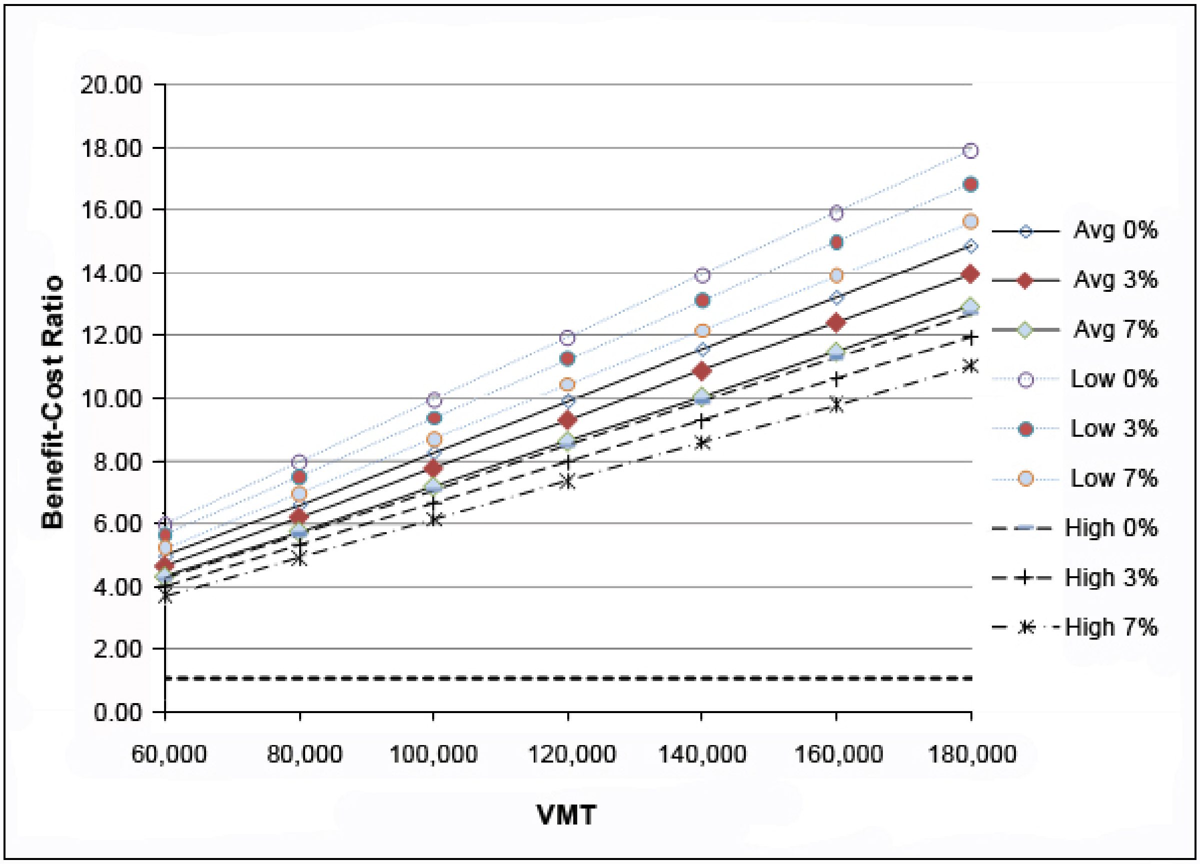

Figure 24. Line Graph. The Estimated Carrier BCR for Trucks With LDW by Initial Cost, Discount Rate, and VMT.

The previous analyses calculated the carrier BCR and NPV during scenarios when LDW was paid in full in year 1. Figure 25 illustrates the impact on the BCR when financing LDW at varying discount rates. In all the scenarios the BCR was greater than "1" when LDW was financed. The specific values for the carrier BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial LDW costs can be found in Appendix H.

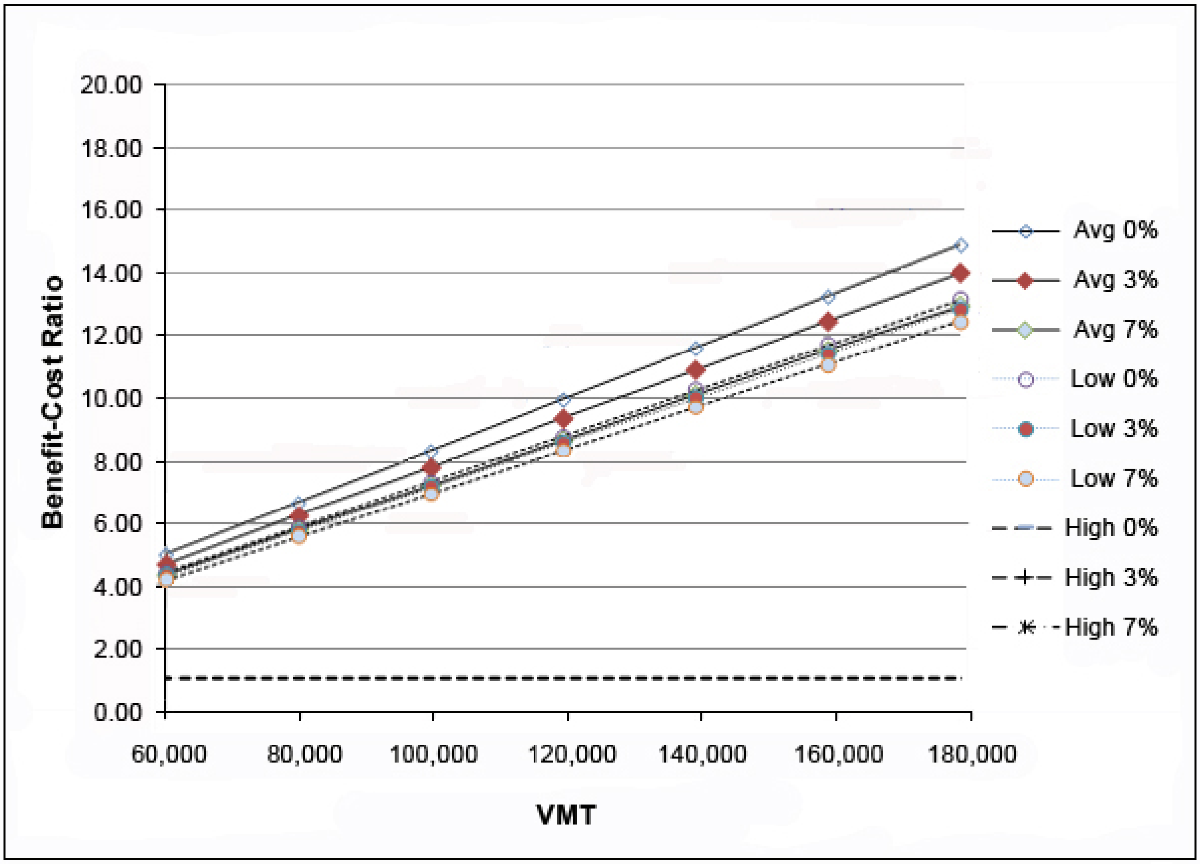

Figure 25. Line Graph. The Estimated Carrier BCR for Trucks With Financed LDW by Discount Rate and VMT.

3.3.1.5 Societal BCA for LDW

A similar BCA was performed to calculate the societal BCR, NPV, and payback periods. Table 38 shows the societal BCR, NPV, and payback periods for purchasing LDW at an average price of $1,000 with varying discount rates. Table 39 shows that the benefits of installing LDW far outweigh the costs regardless of the mileage.

Table 39. The Estimated Societal BCR, NPV, and Payback Periods for Trucks With LDW at an Average Price.

VMT	BCR With 0% Discount	BCR With 3% Discount	BCR With 7% Discount	NPV With 0% Discount	NPV With 3% Discount	NPV With 7% Discount	Payback Period (Months)
60,000	1.90	1.81	1.69	$1,008	$869	$712	32
80,000	2.54	2.41	2.25	$1,717	$1,518	$1,294	24
100,000	3.17	3.01	2.82	$2,426	$2,167	$1,875	19
120,000	3.81	3.61	3.38	$3,134	$2,816	$2,456	16
140,000	4.44	4.21	3.95	$3,843	$3,465	$3,037	14
160,000	5.07	4.81	4.51	$4,551	$4,114	$3,618	12
180,000	5.71	5.42	5.07	$5,260	$4,763	$4,199	11

Figure 26 illustrates the impact on the BCR when varying the initial cost of the LDW and the discount rate. All the scenarios in the figure had a BCR greater than "1." The specific values for the societal BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial LDW costs can be found in Appendix H.

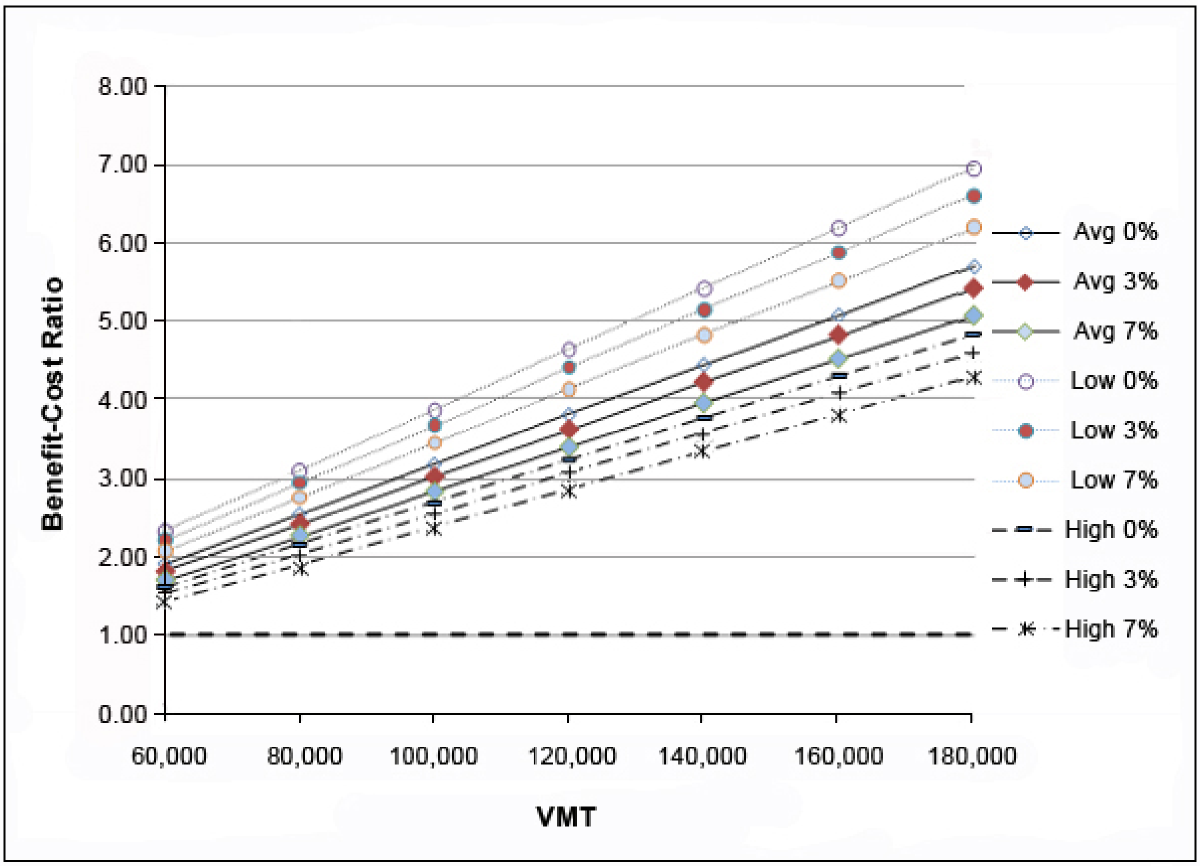

Figure 26. Graph. The Estimated Societal BCR for Trucks With LDW by Initial Cost, Discount Rate, and VMT.

3.3.1.6 Sensitivity Analysis

The following section provides a description of the sensitivity analyses for different analysis periods, mandatory deployment, small carriers, and high-value cargo.

Extended Service Life: Figure 27 illustrates the impact on the carrier extended service life BCR at an average initial cost of LDW and varying discount rates. All of the extended service scenarios in Figure 27 had a BCR greater than "1."

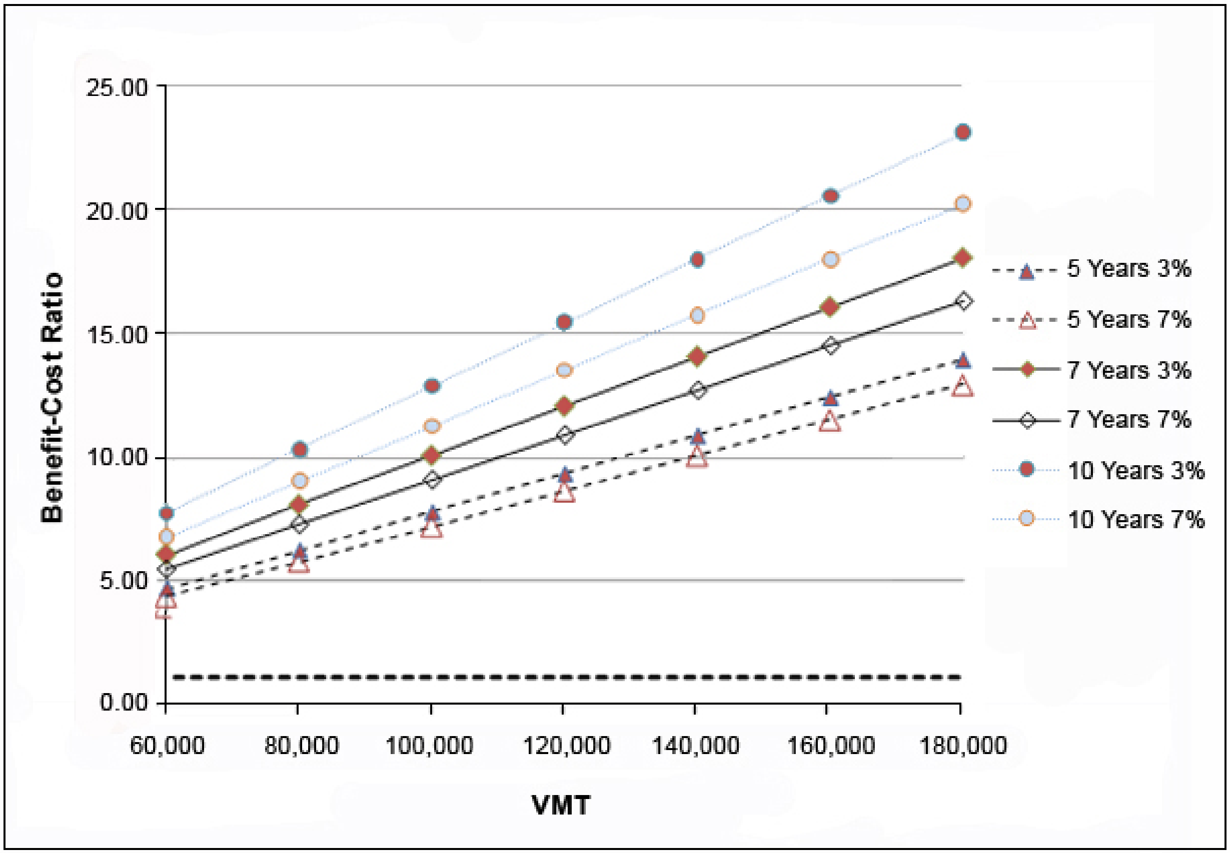

Figure 27. Graph. The Estimated Carrier Extended Service Life BCR for Trucks With LDW at an Average Initial Cost by Discount Rate and VMT.

Figure 28 shows the impact on the societal extended service life BCR at an average initial cost of LDW and varying discount rates. All of the extended service scenarios in Figure 28 had a BCR greater than "1." The specific values for the carrier (extended service life) BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial LDW costs can be found in Appendix H.

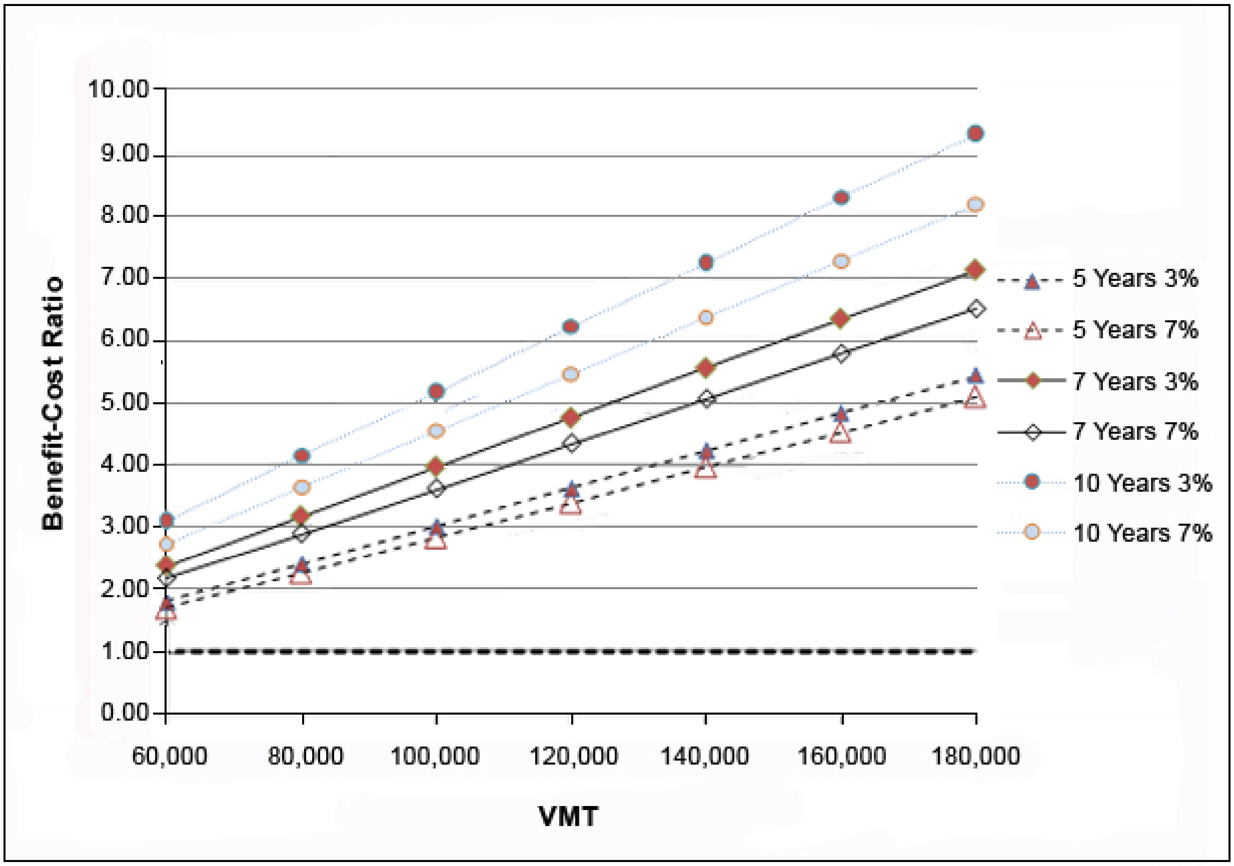

Figure 28. Graph. The Estimated Societal Extended Service Life BCR for Trucks With LDW at an Average Initial Cost by Discount Rate and VMT.

3.3.1.7 Mandatory Deployment of LDW

Table 40 shows the undiscounted costs of mandatory LDW on trucks and the estimated benefits to the carrier over 20 years with a 5-year service life. As shown in the table, the benefits of mandatory LDW deployment far outweigh the costs (BCR of 1.97 over 20 years) to the carrier

Table 40. Estimated Costs and Benefits to the Carrier With Mandatory Deployment of LDW Over 20 Years With a Service Life of 5 Years.

Year	MVMT	Combination Trucks	Number of Drivers	Cost of the LDW (Millions)	Cost of LDW Training (Millions)	Total costs of LDW Deployment (Millions)	Benefit of Avoided LDW-Related Crashes (Millions)
2012	154,542	2,386,234	2,386,234	$2,386*	$56	$2,442	$1,095
2013	158,405	2,445,890	2,445,890	$60	$57	$117	$1,122
2014	162,366	2,507,038	2,507,038	$61	$59	$120	$1,151
2015	166,425	2,569,714	2,569,714	$63	$60	$123	$1,179
2016	170,585	2,633,956	2,633,956	$64	$62	$126	$1,209
2017	174,850	2,699,805	2,699,805	$2,452*	$63	$2,515	$1,239
2018	179,221	2,767,300	2,767,300	$127	$65	$192	$1,270
2019	183,702	2,836,483	2,836,483	$130	$67	$197	$1,302
2020	188,294	2,907,395	2,907,395	$134	$68	$202	$1,334
2021	193,002	2,980,080	2,980,080	$137	$70	$207	$1,368
2022	197,827	3,054,582	3,054,582	$2,527*	$72	$2,598	$1,402
2023	202,772	3,130,946	3,130,946	$204	$73	$277	$1,437
2024	207,842	3,209,220	3,209,220	$209	$75	$284	$1,473
2025	213,038	3,289,451	3,289,451	$214	$77	$291	$1,510
2026	218,364	3,371,687	3,371,687	$219	$79	$208	$1,547
2027	223,823	3,455,979	3,455,979	$2,611*	$81	$2,692	$1,586
2028	229,418	3,542,378	3,542,378	$290	$83	$373	$1,626
2029	235,154	3,630,938	3,630,938	$297	$85	$382	$1,666
2030	241,033	3,721,711	3,721,711	$305	$87	$392	$1,708
2031	247,058	3,814,754	3,814,754	$312	$90	$402	$1,751
TOTAL	N/A	N/A	N/A	$12,800	$1,431	$14,231	$27,974
BCR	N/A	N/A	N/A	N/A	N/A	N/A	1.97

* Cost of LDW includes cost of a new or replacement system every 5 years starting with 2012.

Table 41 shows the undiscounted costs of mandatory LDW on trucks and the estimated benefits to the carrier over 20 years with a 10-year service life. As shown in the table, the benefits of mandatory LDW deployment far outweigh the costs (BCR of 3.40 over 20 years) to the carrier.

Table 41. Estimated Costs and Benefits to the Carrier With Mandatory Deployment of LDW Over 20 Years With a Service Life of 10 Years.

Year	MVMT	Combination Trucks	Number of Drivers	Cost of LDW (Millions)	Cost of LDW Training (Millions)	Total costs of LDW Deployment (Millions)	Benefit of Avoided LDW-Related Crashes (Millions)
2012	154,542	2,386,234	2,386,234	$2,386*	$56	$2,442	$1,095
2013	158,405	2,445,890	2,445,890	$60	$57	$117	$1,122
2014	162,366	2,507,038	2,507,038	$61	$59	$120	$1,151
2015	166,425	2,569,714	2,569,714	$63	$60	$123	$1,179
2016	170,585	2,633,956	2,633,956	$64	$62	$126	$1,209
2017	174,850	2,699,805	2,699,805	$66	$63	$129	$1,239
2018	179,221	2,767,300	2,767,300	$67	$65	$132	$1,270
2019	183,702	2,836,483	2,836,483	$69	$67	$136	$1,302
2020	188,294	2,907,395	2,907,395	$71	$68	$139	$1,334
2021	193,002	2,980,080	2,980,080	$73	$70	$143	$1,368
2022	197,827	3,054,582	3,054,582	$2,461*	$72	$2,532	$1,402
2023	202,772	3,130,946	3,130,946	$136	$73	$210	$1,437
2024	207,842	3,209,220	3,209,220	$139	$75	$215	$1,473
2025	213,038	3,289,451	3,289,451	$143	$77	$220	$1,510
2026	218,364	3,371,687	3,371,687	$146	$79	$226	$1,547
2027	223,823	3,455,979	3,455,979	$150	$81	$231	$1,586
2028	229,418	3,542,378	3,542,378	$154	$83	$237	$1,626
2029	235,154	3,630,938	3,630,938	$158	$85	$243	$1,666
2030	241,033	3,721,711	3,721,711	$162	$87	$249	$1,708
2031	247,058	3,814,754	3,814,754	$166	$90	$255	$1,751
TOTAL	N/A	N/A	N/A	$6,795	$1,431	$8,226	$27,974
BCR	N/A	N/A	N/A	N/A	N/A	N/A	3.40

* Cost of LDW includes cost of a new or replacement system every 10 years starting with 2012.

3.3.1.8 Small Carrier

The costs described in the BCAs above correspond to medium or large carriers; thus, some of the assumptions made with medium and large carriers do not apply to small carriers. One of the critical differences is that most small carriers are not self-insured; thus, the out-of-pocket expenses are significantly lower with deductible values ranging from $5,000 to $50,000.(3) However, it was assumed that 10 percent of labor compensation costs were borne by the small carrier. In addition, driver replacement costs, operational costs for cargo delivery delays, loading and unloading cargo, towing, inventory, storage, and environmental costs were also considered out-of-pocket costs.

Using the same distribution of fatal, injury and PDO crashes as described above, the weighted average cost per LDW-related crash was computed with deductibles of $5,000 and $50,000. Although the costs of deploying LDW were the same, the costs associated with LDW-related crashes in the small carriers were significantly reduced compared to self-insured carriers (as shown in Table 42).

Table 42. Cost per Crash by Severity in Small Carriers With Insurance Deductibles of $5,000 and $50,000

Carrier Type	PDO	Injury	Fatal	Average Cost Per Crash
Self-Insured Carriers	$122,054	$331,035	$1,108,547	$137,672
Small Carriers (Deductible $50,000)	$94,178	$123,363	$108,538	$95,500
Small Carriers (Deductible $5,000)	$48,202	$77,387	$62,562	$49,524

Figure 29 illustrates the impact on the carrier BCR in a small carrier with a $5,000 deductible when varying the initial cost of LDW and discount rate. All of the scenarios had a BCR greater than “1.”

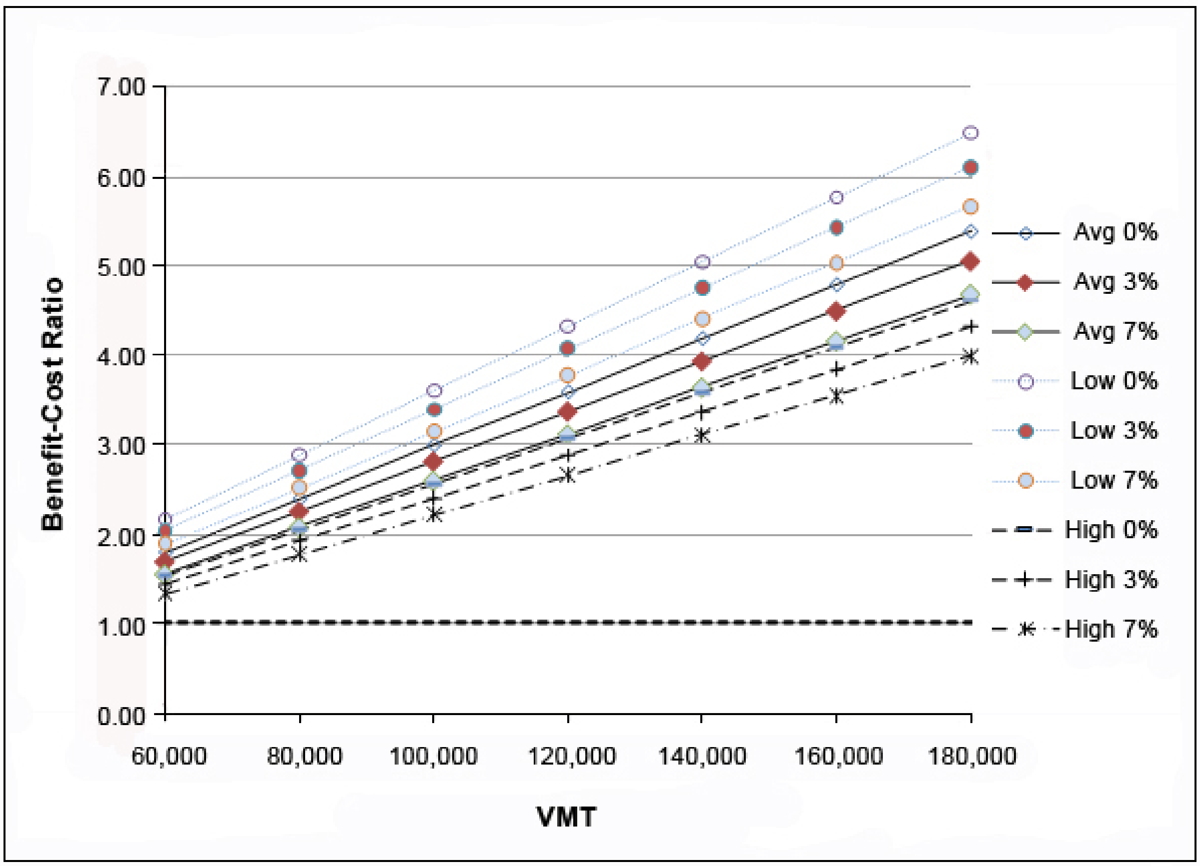

Figure 29. Graph. The Estimated Carrier BCR for Small Carriers With a $5,000 Deductible That Have Trucks With LDW by Initial Cost, Discount Rate, and VMT

Figure 30 illustrates the impact on the carrier BCR in a small carrier with a $50,000 deductible when varying the initial cost of LDW and discount rate. All of the scenarios had a BCR greater than "1." The specific values for the carrier (small carrier) BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial LDW costs can be found in Appendix H.

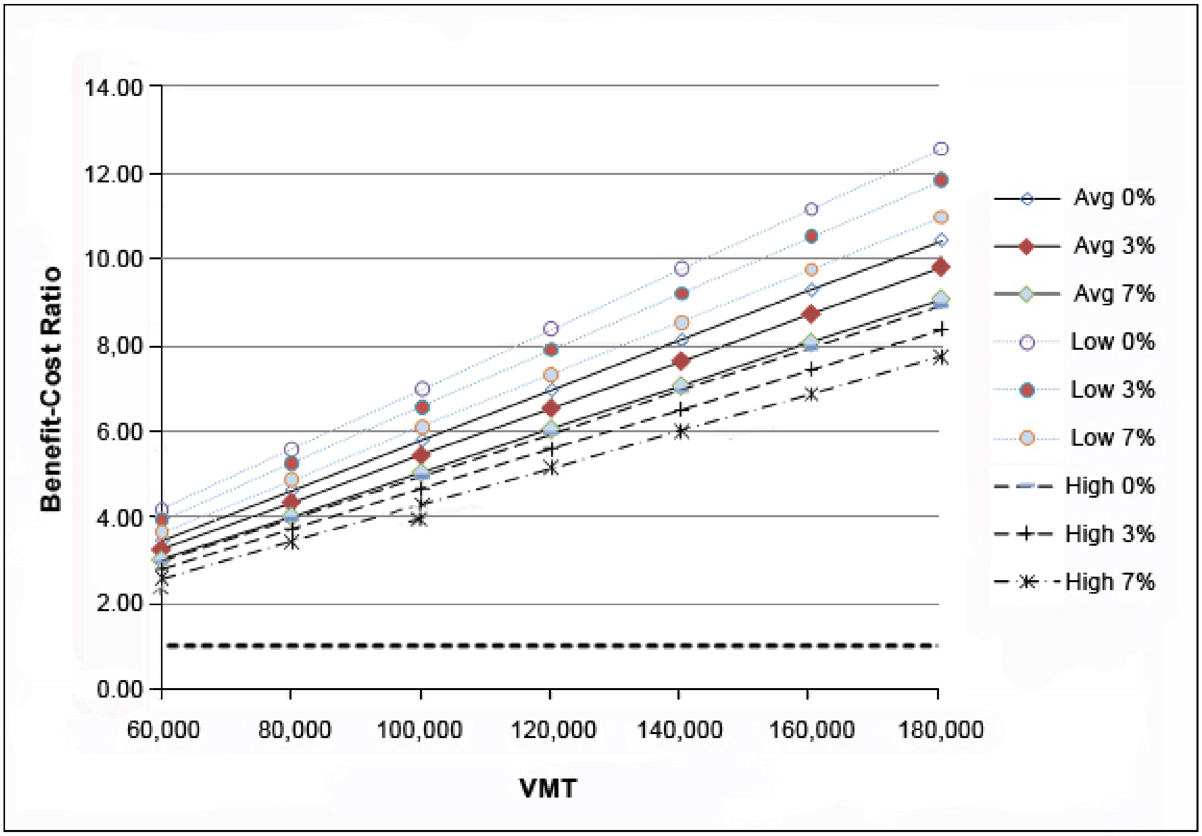

Figure 30. Line Graph. The Estimated Carrier BCR for Small Carriers With a $50,000 Deductible That Have Trucks With LDW by Initial Cost, Discount Rate, and VMT.

3.3.2 RSC System

The following Section describes the BCA for RSC.

3.3.2.1 Technology and Deployment Costs

The low, mean, and high estimated costs for RSC shown in Table 43 included $300, $500, and $700, respectively. These costs assume the RSC system was paid in full in year 1. Although this was the assumption in the societal BCA, it was also possible that carriers financed the technology (where the costs of RSC increased on a yearly basis). An average interest rate of 6.38 percent[(9)] and a loan period of 3 years was used to compute the financed costs of the RSC.

Table 43. Initial Cost and Cost Variation of Financing Over 3 Years for RSC.

Option	Initial Cost	Year 1	Year 2	Year 3	Total Cost Financed
Low Cost Estimate	$300	$111	$111	$111	$332
Average Cost Estimate	$500	$184	$184	$184	$551
High Cost Estimate	$700	$257	$257	$257	$771

Figure 31 shows the RSC price range variability for different discount rates. Although the average interest rate can vary, this variation in the average interest rate made little difference in the estimated cost of RSC considered in the current analysis (i.e., average, low, and high).

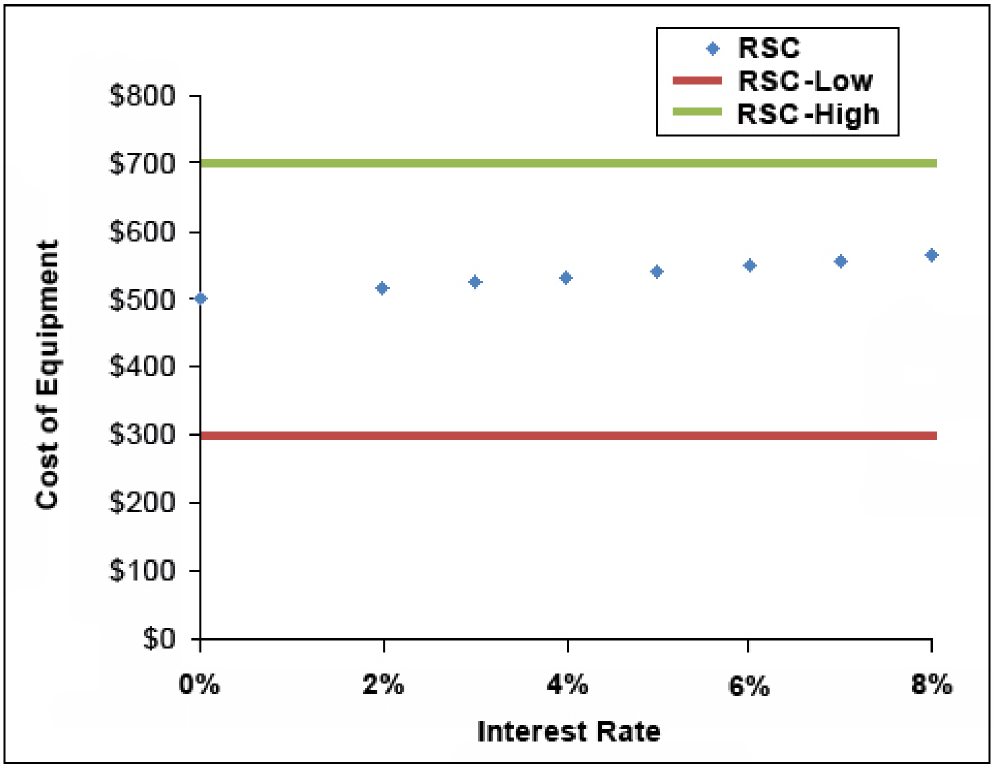

Figure 31. Chart. RSC Price Range Variability for Different Discount Rates With an Original Equipment Cost of $500 (f = Financed).

A tax rate of 35 percent was used to compute the Federal tax savings due to depreciation of RSC. The MACRS was used to estimate property depreciation following the instructions in IRS.[51] Table 44 shows the 5-year Federal tax savings due to the depreciation of RSC. These costs were negative as it was a discount of the total cost of RSC. This depreciation was only calculated in the carrier BCA and not the societal BCA.

Table 44. Federal Tax Savings Due to the Depreciation of RSC.

Cost Estimate	Year 1	Year 2	Year 3	Year 4	Year 5
Low Cost Estimate	-$35.00	-$46.67	-$15.55	-$7.78	$0.00
Average Cost Estimate	-$58.33	-$77.79	-$25.92	-$12.97	$0.00
High Cost Estimate	-$81.66	-$108.90	-$36.28	-$18.15	$0.00

The time spent in RSC training varied from 15 minutes to 2 hours. An average training time of 1 hour was used in the BCAs. The cost of the drivers' time was computed using the 50th percentile driver salary from the Bureau of Labor Statistics ($17.92 per hour).[49] This rate was adjusted upward by 31 percent to cover fringe benefits,[9,35] thereby resulting in a total hourly cost of $23.47. Given the high attrition rate in the trucking industry, it was assumed that driver training was conducted on an annual basis. Table 45 and Table 46 show the total cost of RSC deployment in the carrier and societal BCAs, respectively (where f = financed). The tables show that for an average estimated cost of $500 for RSC, the total costs of RSC deployment in the carrier BCA was $442.38 ($493.09 if financing) and $617 for RSC deployment in the societal BCA.

Table 45. Total Cost of RSC Deployment in the Carrier BCA (Average Cost of $500).

Price	Option	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Low Cost Estimate	RSC	$288.48	-$23.20	$7.92	$15.69	$23.48	$312.38
Low Cost Estimate	RSC (f)	$98.98	$87.30	$118.42	$15.69	$23.48	$343.88
Average Cost Estimate	RSC	$465.15	-$54.31	-$2.44	$10.51	$23.48	$442.38
Average Cost Estimate	RSC (f)	$148.72	$129.26	$181.13	$10.51	$23.48	$493.09
High Cost Estimate	RSC	$641.82	-$85.43	-$12.81	$5.32	$23.48	$572.38
High Cost Estimate	RSC (f)	$198.82	$171.57	$244.19	$5.32	$23.48	$643.38

Table 46. Total Cost of RSC Deployment in the Societal BCA (Average Cost of $500).

Price	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Low Cost Estimate	$323.48	$23.48	$23.48	$23.48	$23.48	$417.38
Average Cost Estimate	$523.48	$23.48	$23.48	$23.48	$23.48	$617.38
High Cost Estimate	$723.48	$23.48	$23.48	$23.48	$23.48	$817.38

The NPV for RSC was computed using discount rates of 3 percent and 7 percent. Table 47 and Table 48 show the NPV for the total costs of RSC deployment in the carrier and societal BCAs, respectively (where f = financed).

Table 47. NPV for the Total Costs of RSC by Discount Rates in the Carrier BCA

Price	Option	0% Discount Rate	3% Discount Rate	7% Discount Rate
Low	RSC	$1,092.38	$1,068.25	$1,037.61
Low	RSC (f)	$1,244.48	$1,169.65	$1,080.95
Average	RSC	$1,417.38	$1,388.50	$1,351.40
Average	RSC (f)	$1,620.19	$1,523.71	$1,409.20
High	RSC	$1,742.38	$1,708.74	$1,665.18
High	RSC (f)	$1,995.78	$1,877.66	$1,737.33

Table 48. NPV of the Total Costs of RSC by Discount Rates in the Societal BCA

Price	Option	0% Discount Rate	3% Discount Rate	7% Discount Rate
Low	RSC	$1,617.38	$1,563.82	$1,498.12
Average	RSC	$2,117.38	$2,049.26	$1,965.41
High	RSC	$2,617.38	$2,534.69	$2,432.70

Figure 32 shows the impact on the total cost of RSC with an increase in the number of drivers from 1 driver per truck to 1.5 and 2 drivers per truck, and turnover rates of 200 percent and 25 percent (with an average cost of $500 for RSC and discount rates of 0, 3, and 7 percent). The variability in these costs was not significant and was always less than the variability in equipment costs associated with RSC (i.e., low, average, and high). For example, with an RSC cost of $500 and a discount rate of 0 percent, the costs for 1, 1.5, and 2 drivers per truck were $442.38, $501.06, and $559.75, respectively. Similar costs were obtained with different discount rates and retention rates.

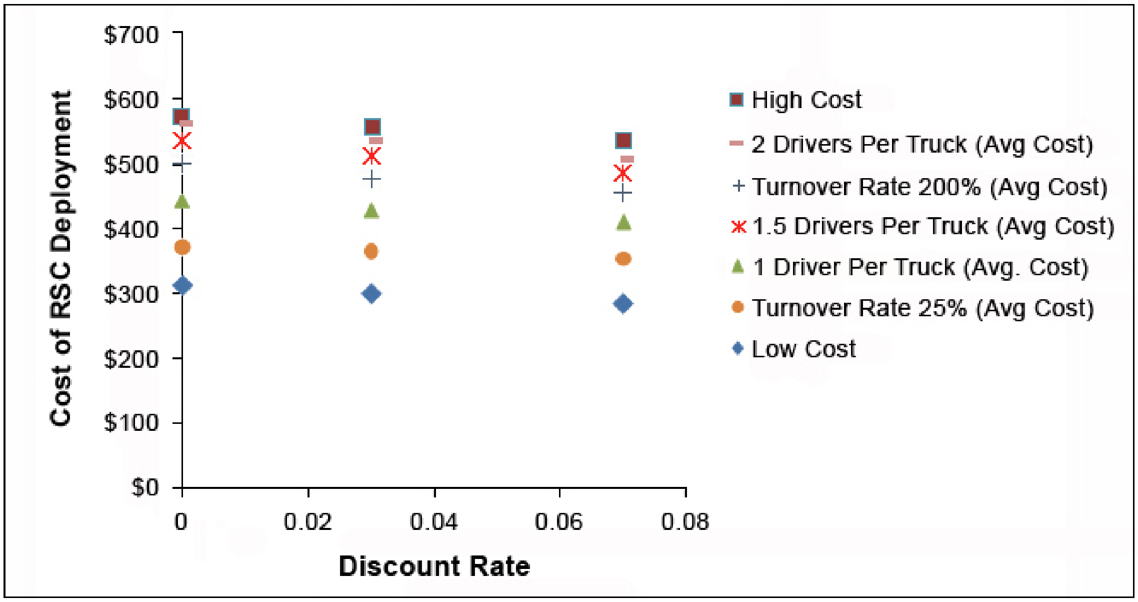

Figure 32. Chart. Influence of Salary, Discount Rates, and Turnover Rates on RSC Deployment Costs.

3.3.2.2 Crash Avoidance Benefits

The following section describes the types of crash avoidance benefits that were included in the carrier and societal BCAs.

Carrier Crash Avoidance Benefits: Table 48 shows the carrier crash avoidance benefits used in the current study were the values of the crashes reported in Murray et al.,[9] using the GDP deflator (based on 2008 U.S. dollars). These values assumed the carrier was self-insured or maintained a per-crash deductible that exceeded total crash costs. PDO crashes were the least expensive (with a total value of $201,230 per crash), injury crashes were valued to the carrier at $472.502, and fatal crashes were valued to the carrier at $1,167,811. Labor and workers' compensation applied only when the truck driver involved in the crash was injured or killed. These costs assumed there were 0.10 driver injuries per injury crash and 0.4 driver fatalities per fatal crash. To compute the average settlement costs per injury and fatal rear-end crash it was assumed that there are 1.3 injuries per injury crash, 1.1 injuries per fatal crash, and 1 fatality per fatal crash.[9]

Table 49. Cost Estimates Per Rollover Crash, by Crash Severity.

Cost Category	PDO Crash	Injury Crash	Fatal Crash
Labor and Workers' Compensation	N/A	$71,241	$49,868
Operational	$29,246	$29,246	$29,246
Environmental	$84,290	$84,290	$84,290
Property Damage	$57,044	$57,044	$57,044
Legal Settlement	N/A	$194,923	$834,977
Court Costs and Other Legal Fees	$30,651	$35,759	$112,386
Total	$201,230	$472,502	$1,167,811

To determine the average crash avoidance benefits for crashes involving large trucks that were avoided by RSC, the weighted average was computed using the severity distributions in the current dataset (PDO, injury, and fatal) that were avoided with RSC. As indicated earlier in this report, this distribution of RSC-related crashes resulted in 81.96 percent PDO crashes, 17.44 percent injury crashes, and 0.6 percent fatal crashes. Thus, the resultant weighted average crash avoidance benefit per RSC-related crash was $254,772.

Societal Crash Avoidance Benefit: Table 39 shows how the societal costs were computed using the values provided by FMCSA. These values correspond to the values reported in Zaloshnja and Miller,[48] but were modified with a VSL of $6,000,000 and adjusted to 2008 U.S. dollars using the GDP deflator.

Crash avoidance benefits are specified for each of the KABCO severity ratings in Table 34. To compute the crash avoidance benefits in injury crashes, a weighted average was computed using category C (possible injury), category B (non-incapacitating injury), category A (incapacitating injury), and category U (injury severity unknown) that resulted in an average crash avoidance benefit of $334,888. The crash avoidance benefits for fatal crashes correspond with category K (killed), and for PDO crashes with category O (no injury) for total values of $7,633,600 and $18,643, respectively. (Note that the PDO crash avoidance benefit to society of $18,643 is about 9 percent of the total PDO crash cost of $201,230 [Table 49] to the carrier because the PDO crash avoidance benefit to society does not include avoided court and legal fees, operational, and environmental considerations.) To compute the average benefit per crash, the weighted average of the distribution of RSC-related crashes (property, injury and fatal) in the current study database was used. This resulted in an average benefit of $120,088 for an avoided RSC-related crash.

3.3.2.3 Identify Crash Avoidance Benefits as a Reduction in the Crash Rate

The crash rate was computed as the difference between the RSC-related crash rate in the non-RSC cohort (0.064 crashes per MVMT) and the RSC cohort (0.04 crashes per MVMT; difference = 0.024 crashes per MVMT). Table 50 shows the average carrier and societal savings in crash cost per truck/year with a 0 percent discount rate (as well as the 5-year total) for RSC. For example, the savings in the reduction of RSC-related crashes for carriers with RSC installed on a truck that travels an average of 100,000 miles per year was $614 per year ($3,072 per truck over the 5-year analysis period). Due to rounding, the 5-year totals for carrier and societal costs in Table 50 may not reflect the per-year costs multiplied by five.

Table 50. Undiscounted Average Savings in the Reduction of RSC-Related Crashes With RSC.

VMT	Per Year for Carriers	5-Year Total for Carriers	Per Year for Society	5-Year Total for Society
60,000	$369	$1,843	$174	$869
80,000	$492	$2,458	$232	$1,159
100,000	$614	$3,072	$290	$1,448
120,000	$737	$3,687	$348	$1,738
140,000	$860	$4,301	$405	$2,027
160,000	$983	$4,916	$463	$2,317
180,000	$1,106	$5,530	$521	$2,607

Table 51 shows the average carrier crash cost per truck with RSC in the 5-year analysis period with discount rates of 3 percent and 7 percent.

Table 51. Discounted Average Carrier Savings Over 5 Years in the Reduction of RSC-Related Crashes With RSC.

VMT	0% Discount Rate	3% Discount Rate	7% Discount Rate
60,000	$1,843	$1,688	$1,512
80,000	$2,458	$2,251	$2,016
100,000	$3,072	$2,814	$2,519
120,000	$3,687	$3,377	$3,023
140,000	$4,301	$3,940	$3,527
160,000	$4,916	$4,502	$4,031
180,000	$5,530	$5,065	$4,535

Table 52 shows the average societal crash cost per truck with RSC in the 5-year analysis period with discount rates of 3 percent and 7 percent.

Table 52. Discounted Average Societal Savings Over 5 Years in the Reduction of RSC-Related Crashes With RSC

VMT	0% Discount Rate	3% Discount Rate	7% Discount Rate
60,000	$869	$796	$713
80,000	$1,159	$1,061	$950
100,000	$1,448	$1,326	$1,188
120,000	$1,738	$1,592	$1,425
140,000	$2,027	$1,857	$1,663
160,000	$2,317	$2,122	$1,900
180,000	$2,607	$2,388	$2,138

The following sections describe the measures in the BCA that were computed to compare the benefits and costs in implementing RSC, including: NPV of the different alternatives, BCR, and payback periods. The BCR, NPV, and payback periods were computed for various scenarios, including: carrier and society; discount rates of 0, 3, and 7 percent; low, average, and high technology costs; with and without financing; and various VMTs (60,000 to 180,000 miles per year). In addition, several scenarios were calculated in the sensitivity analysis for a longer analysis period, mandatory deployment, small carriers, and high-value cargo.

3.3.2.4 Carrier BCA for Roll Stability Control

Table 53 shows the carrier BCR, NPV, and payback periods for purchasing RSC at an average price of $500 by varying discount rates (without financing). Table 53 shows that the benefits of installing RSC outweigh the costs in all scenarios (the BCR was greater than "1" or the NPV was positive).

Table 53. The Estimated Carrier BCR, NPV, and Payback Periods for Trucks With RSC at an Average Price (Without Financing)

VMT	BCR With 0% Discount	BCR With 3% Discount	BCR With 7% Discount	NPV With 0% Discount	NPV With 3% Discount	NPV With 7% Discount	Payback Period (Months)
60,000	4.17	3.95	3.69	$1,401	$1,261	$1,102	14
80,000	5.56	5.26	4.92	$2,015	$1,823	$1,605	11
100,000	6.95	6.58	6.14	$2,630	$2,386	$2,109	9
120,000	8.33	7.89	7.37	$3,244	$2,949	$2,613	7
140,000	9.72	9.21	8.60	$3,859	$3,512	$3,117	6
160,000	11.11	10.53	9.83	$4,473	$4,075	$3,621	5
180,000	12.50	11.84	11.06	$5,088	$4,638	$4,125	5

Figure 33 illustrates the impact on the BCR when varying the initial cost of the RSC and the discount rate. The dotted horizontal line illustrates when the BCR was "1" (i.e., where the benefits of installing RSC equal the benefits accrued as a reduction in crash costs over the 5-year analysis period). It also shows that the benefits of installing RSC outweigh the costs in all scenarios.

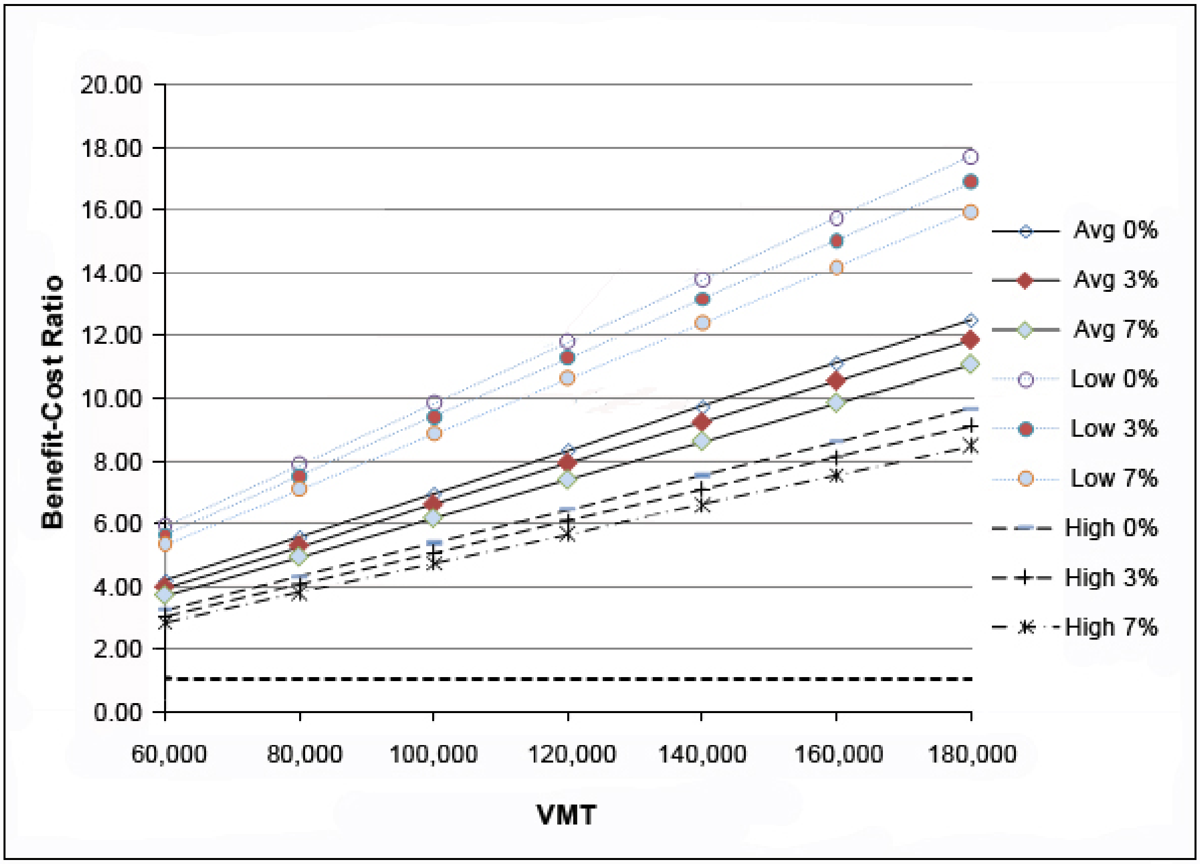

Figure 33. Line Graph. The Estimated Carrier BCR for Trucks With RSC by Initial Cost, Discount Rate, and VMT.

The previous analyses calculated carrier BCR and NPV during scenarios when RSC was paid in full in year 1. Figure 34 illustrates the impact on the BCR when financing RSC at varying discount rates. Similarly, in all the scenarios in Figure 34 the BCR was greater than “1” when RSC was financed. The specific values for the carrier BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial RSC costs can be found in Appendix H.

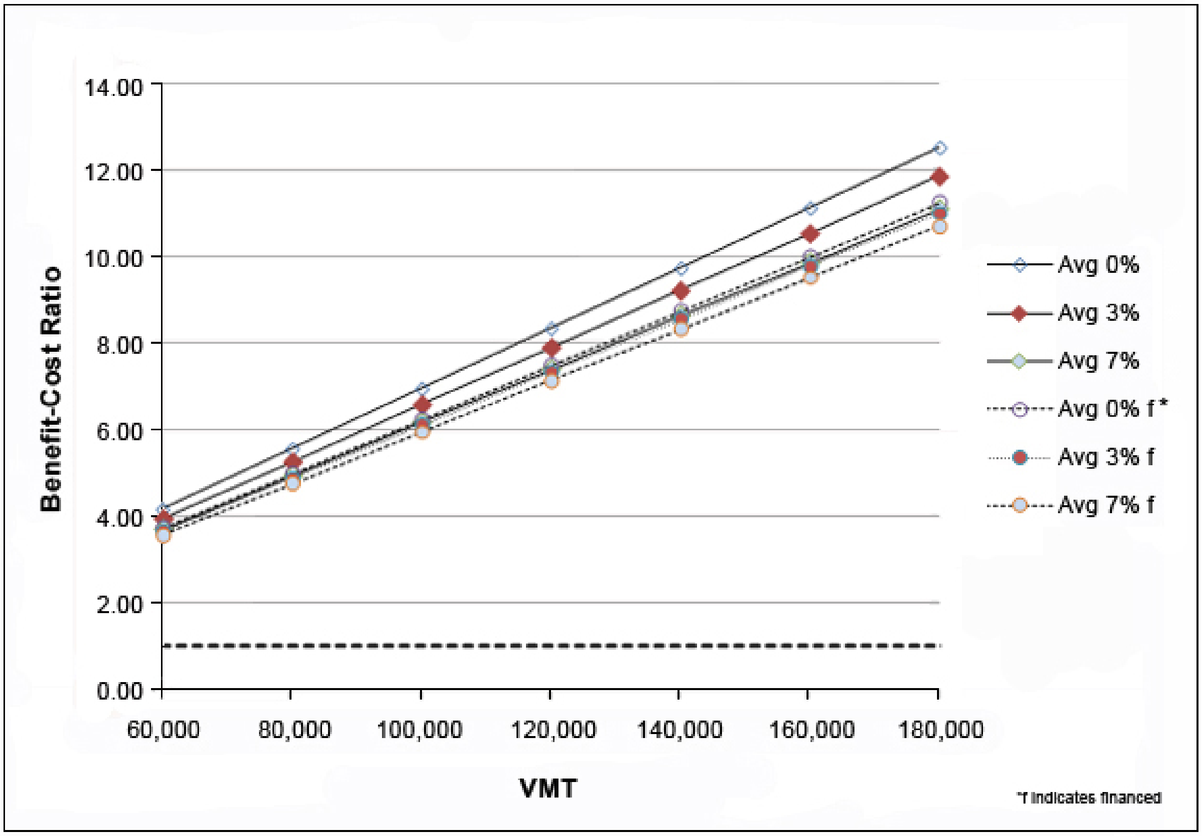

Figure 34. Line Graph. The Estimated Carrier BCR for Trucks With Financed RSC by Discount Rate and VMT.

3.3.2.5 Societal BCA for Roll Stability Control

A similar BCA was performed to calculate the societal BCR, NPV, and payback periods. Table 53 shows the societal BCR, NPV, and payback periods for purchasing RSC at an average price of $500 with varying discount rates. Table 54 shows that the benefits of installing RSC outweigh the costs in all scenarios.

Table 54. The Estimated Societal BCR, NPV, and Payback Periods for Trucks With RSC at an Average Price.

VMT	BCR With 0% Discount	BCR With 3% Discount	BCR With 7% Discount	NPV With 0% Discount	NPV With 3% Discount	NPV With 7% Discount	Payback Period (Months)
60,000	1.41	1.34	1.26	$252	$203	$149	43
80,000	1.88	1.79	1.69	$541	$468	$386	32
100,000	2.35	2.24	2.11	$831	$733	$624	26
120,000	2.81	2.68	2.53	$1,120	$999	$861	21
140,000	3.28	3.13	2.95	$1,410	$1,264	$1,099	18
160,000	3.75	3.58	3.37	$1,700	$1,529	$1,337	16
180,000	4.22	4.03	3.79	$1,989	$1,795	$1,574	14

Figure 35 illustrates the impact on the BCR when varying the initial cost of the RSC and the discount rate. In all the scenarios in Figure 34, the BCR was greater than "1." The specific values for the societal BCR, NPV, and payback periods for varying VMTs, discount rates, and initial RSC costs can be found in Appendix H.

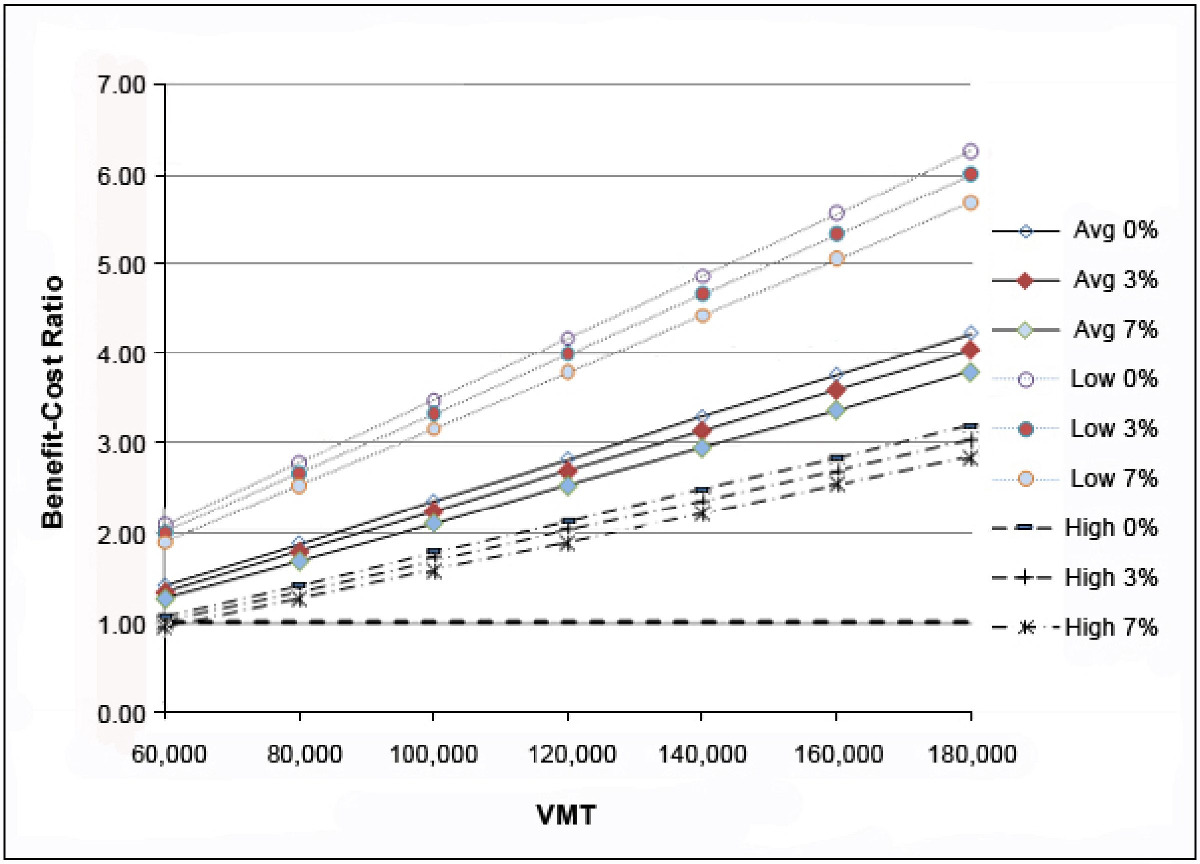

Figure 35. Line Graph. The Estimated Societal BCR for Trucks With RSC by Initial Cost, Discount Rate, and VMT.

3.3.2.6 Sensitivity Analysis

The following Section provides a description of the sensitivity analyses for different analysis periods, mandatory deployment, small carriers, and high-value cargo.

Extended Service Life: Figure 36 illustrates the impact on the carrier extended service life BCR at an average initial cost of RSC and varying discount rates. All of the extended service scenarios had a BCR greater than "1."

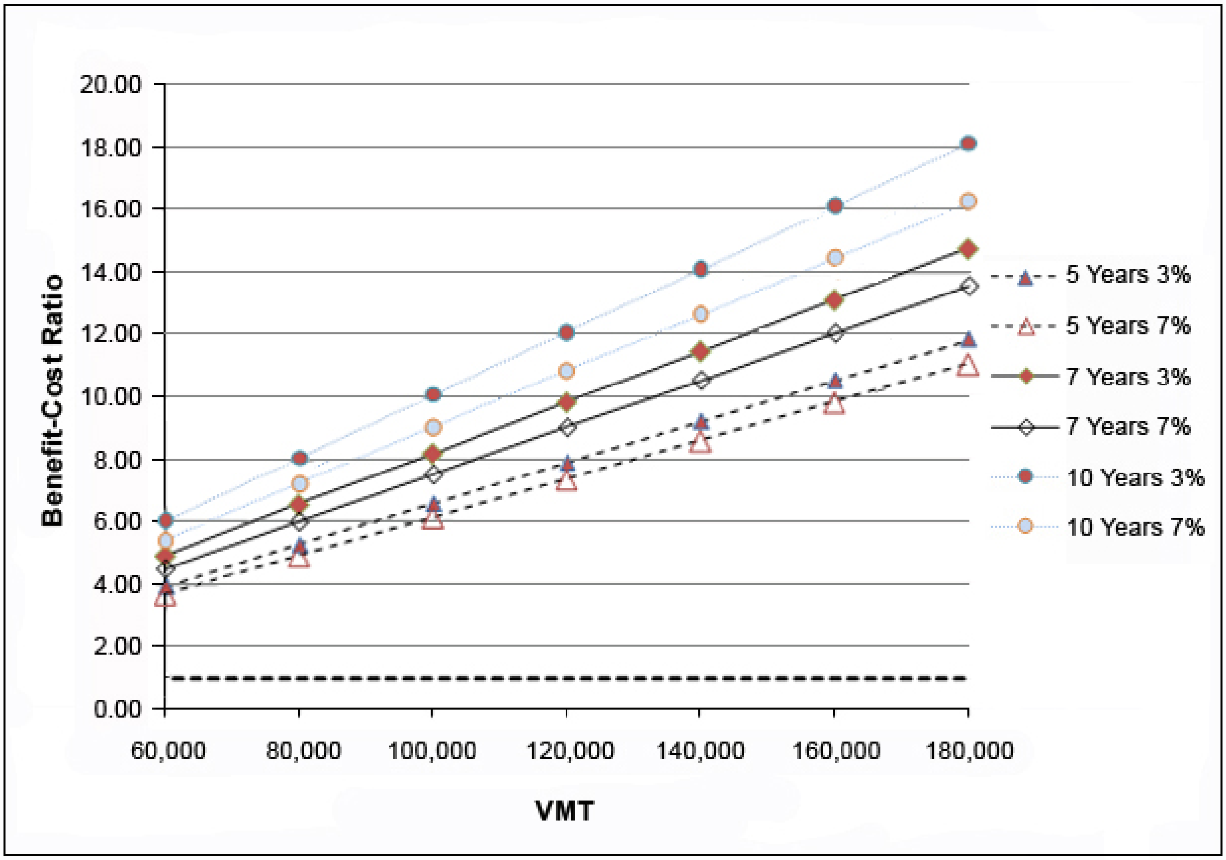

Figure 36. Line Graph. The Estimated Carrier Extended Service Life BCR for Trucks With RSC at an Average Initial Cost by Discount Rate and VMT.

Figure 37 illustrates the impact on the societal extended service life BCR at an average initial cost of RSC and varying discount rates. When the service life of RSC was extended to 10 years with discount rates of 3 and 7 percent, the BCR was greater than “1” when the truck traveled at least 60,000 miles per year. The specific values for the carrier (extended service life) BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial RSC costs can be found in Appendix H.

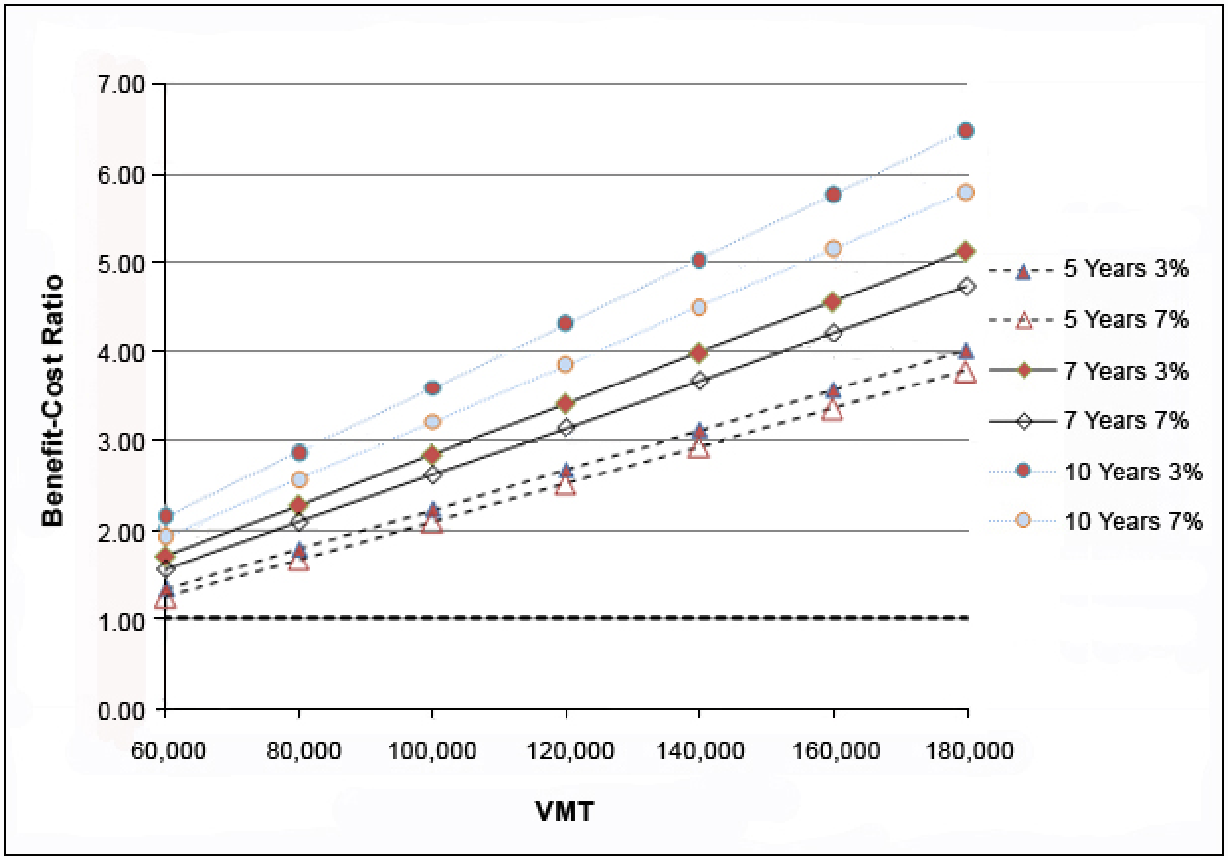

Figure 37. Line Graph. The Estimated Societal Extended Service Life BCR for Trucks With RSC at an Average Initial Cost by Discount Rate and VMT.

3.3.2.7 Mandatory Deployment of Roll Stability Control

Table 55 shows the undiscounted costs of mandatory RSC on trucks and the estimated benefits over 20 years with a 5-year service life. As shown, the benefits of mandatory RSC deployment outweigh the costs (BCR of 1.46 over 20 years) to carriers.

Table 55. Estimated Costs and Benefits to Carriers With Mandatory Deployment of RSC Over 20 Years With a Service Life of 5 Years.

Year	MVMT	Combination Trucks	Number of Drivers	Cost of the RSC (Millions)	Cost of RSC Training (Millions)	Total costs of RSC Deployment (Millions)	Benefit of Avoided RSC-Related Crashes (Millions)
2012	154,542	2,386,234	2,386,234	$1,193*	$56	$1,249	$448
2013	158,405	2,445,890	2,445,890	$30	$57	$87	$459
2014	162,366	2,507,038	2,507,038	$31	$59	$89	$470
2015	166,425	2,569,714	2,569,714	$31	$60	$92	$482
2016	170,585	2,633,956	2,633,956	$32	$62	$94	$494
2017	174,850	2,699,805	2,699,805	$1,126*	$63	$1,289	$506
2018	179,221	2,767,300	2,767,300	$64	$65	$129	$519
2019	183,702	2,836,483	2,836,483	$65	$67	$132	$532
2020	188,294	2,907,395	2,907,395	$67	$68	$135	$545
2021	193,002	2,980,080	2,980,080	$68	$70	$138	$559
2022	197,827	3,054,582	3,054,582	$1,263*	$72	$1,335	$573
2023	202,772	3,130,946	3,130,946	$102	$73	$175	$587
2024	207,842	3,209,220	3,209,220	$104	$75	$180	$602
2025	213,038	3,289,451	3,289,451	$107	$77	$184	$617
2026	218,364	3,371,687	3,371,687	$110	$79	$189	$632
2027	223,823	3,455,979	3,455,979	$1,305*	$81	$1,387	$648
2028	229,418	3,542,378	3,542,378	$145	$83	$228	$664
2029	235,154	3,630,938	3,630,938	$149	$85	$234	$681
2030	241,033	3,721,711	3,721,711	$152	$87	$240	$698
2031	247,058	3,814,754	3,814,754	$156	$90	$246	$716
TOTAL	N/A	N/A	N/A	$6,400	$1,431	$7,831	$11,434
BCR	N/A	N/A	N/A	N/A	N/A	N/A	1.46

* Cost of RSC includes cost of new or replacement system every 5 years starting with 2012.

Table 56 shows the undiscounted costs of mandatory RSC on trucks and the estimated benefits over 20 years with a 10-year service life. As shown, the benefits of mandatory RSC deployment far outweigh the costs (BCR of 2.37 over 20 years).

Table 56. Estimated Costs and Benefits to Carriers with Mandatory Deployment of RSC Over 20 Years With a Service Life of 10 Years.

Year	MVMT	Combination Trucks	Number of Drivers	Cost of the RSC (Millions)	Cost of RSC Training (Millions)	Total costs of RSC Deployment (Millions)	Benefit of Avoided RSC-Related Crashes (Millions)
2012	154,542	2,386,234	2,386,234	$1,193*	$56	$1,249	$448
2013	158,405	2,445,890	2,445,890	$30	$57	$87	$459
2014	162,366	2,507,038	2,507,038	$31	$59	$89	$470
2015	166,425	2,569,714	2,569,714	$31	$60	$92	$482
2016	170,585	2,633,956	2,633,956	$32	$62	$94	$494
2017	174,850	2,699,805	2,699,805	$33	$63	$96	$506
2018	179,221	2,767,300	2,767,300	$34	$65	$99	$519
2019	183,702	2,836,483	2,836,483	$35	$67	$101	$532
2020	188,294	2,907,395	2,907,395	$35	$68	$104	$545
2021	193,002	2,980,080	2,980,080	$36	$70	$106	$559
2022	197,827	3,054,582	3,054,582	$1,230*	$72	$1,302	$573
2023	202,772	3,130,946	3,130,946	$68	$73	$142	$587
2024	207,842	3,209,220	3,209,220	$70	$75	$145	$602
2025	213,038	3,289,451	3,289,451	$71	$77	$149	$617
2026	218,364	3,371,687	3,371,687	$73	$79	$152	$632
2027	223,823	3,455,979	3,455,979	$75	$81	$156	$648
2028	229,418	3,542,378	3,542,378	$77	$83	$160	$664
2029	235,154	3,630,938	3,630,938	$79	$85	$164	$681
2030	241,033	3,721,711	3,721,711	$81	$87	$168	$698
2031	247,058	3,814,754	3,814,754	$83	$90	$172	$716
TOTAL	N/A	N/A	N/A	$3,397	$1,431	$4,828	$11,434
BCR	N/A	N/A	N/A	N/A	N/A	N/A	2.37

* Cost of RSC includes cost of new or replacement system every 10 years starting with 2012

3.3.2.8 Small Carrier

Using the same distribution of fatal, injury and PDO crashes as described above, the weighted average cost per RSC-related crash was computed with deductibles of $5,000 and $50,000. Although the costs in deploying RSC were the same, the costs associated with RSC-related crashes in the small carriers were significantly reduced compared to self-insured carriers (as shown in Table 57).

Table 57. Cost per Rollover Crash by Severity in Small Carriers with an Insurance Deductible of $5,000 and $50,000.

Carrier	PDO	Injury	Fatal	Average Cost Per Crash
Self-Insured Carriers	$201,230	$472,502	$1,167,811	$254,772
Small Carriers (Deductible $50,000)	$148,210	$161,771	$157,703	$150,653
Small Carriers (Deductible $5,000)	$103,210	$116,771	$112,703	$105,653

Figure 38 illustrates the impact on the carrier BCR in a small carrier with a $5,000 deductible when varying the initial cost of RSC and discount rate. All of the scenarios had a BCR greater than "1."

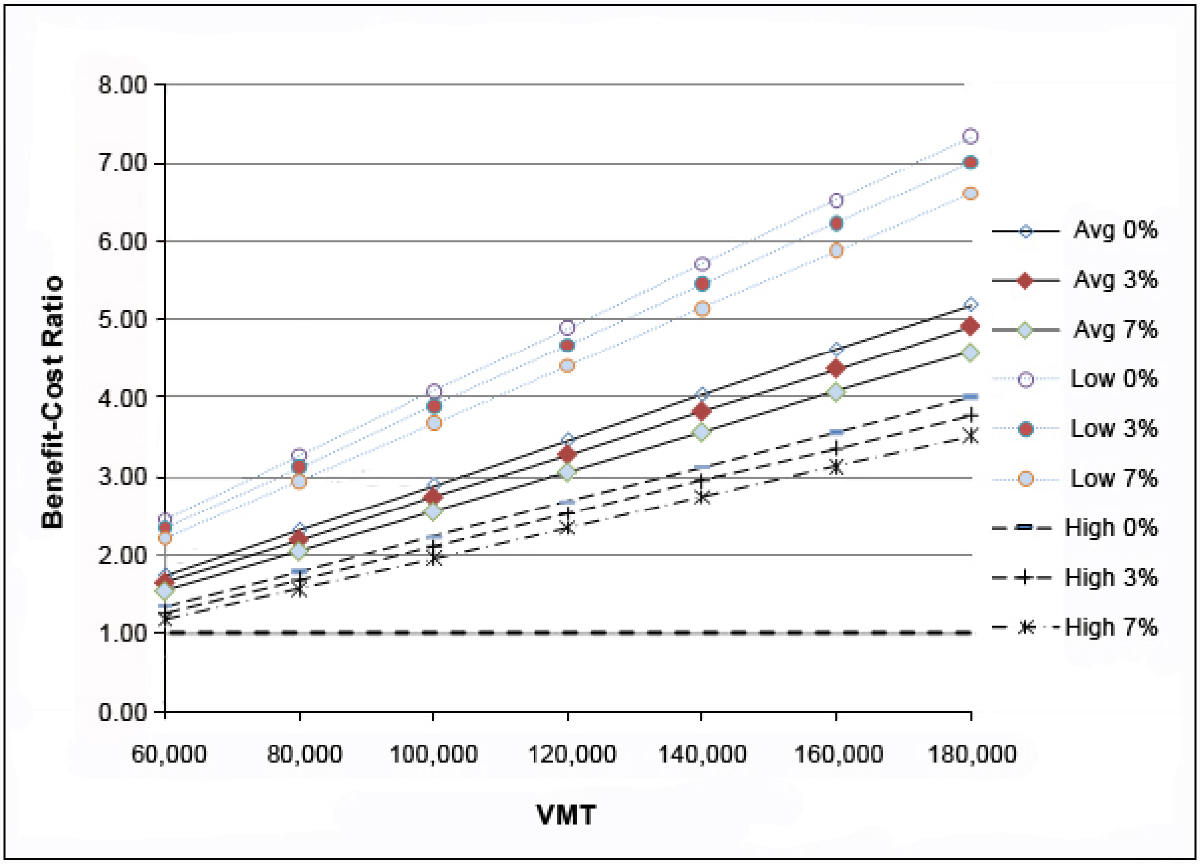

Figure 38. Line Graph. The Estimated Carrier BCR for Small Carriers With a $5,000 Deductible That Have Trucks With RSC by Initial Cost, Discount Rate, and VMT.

Figure 39 illustrates the impact on the carrier BCR in a small carrier with a $50,000 deductible when varying the initial cost of RSC and discount rate. All of the scenarios had a BCR greater than "1." The specific values for the carrier (small carrier) BCR, NPV, and payback periods (with and without financing) for varying VMTs, discount rates, and initial RSC costs can be found in Appendix H.

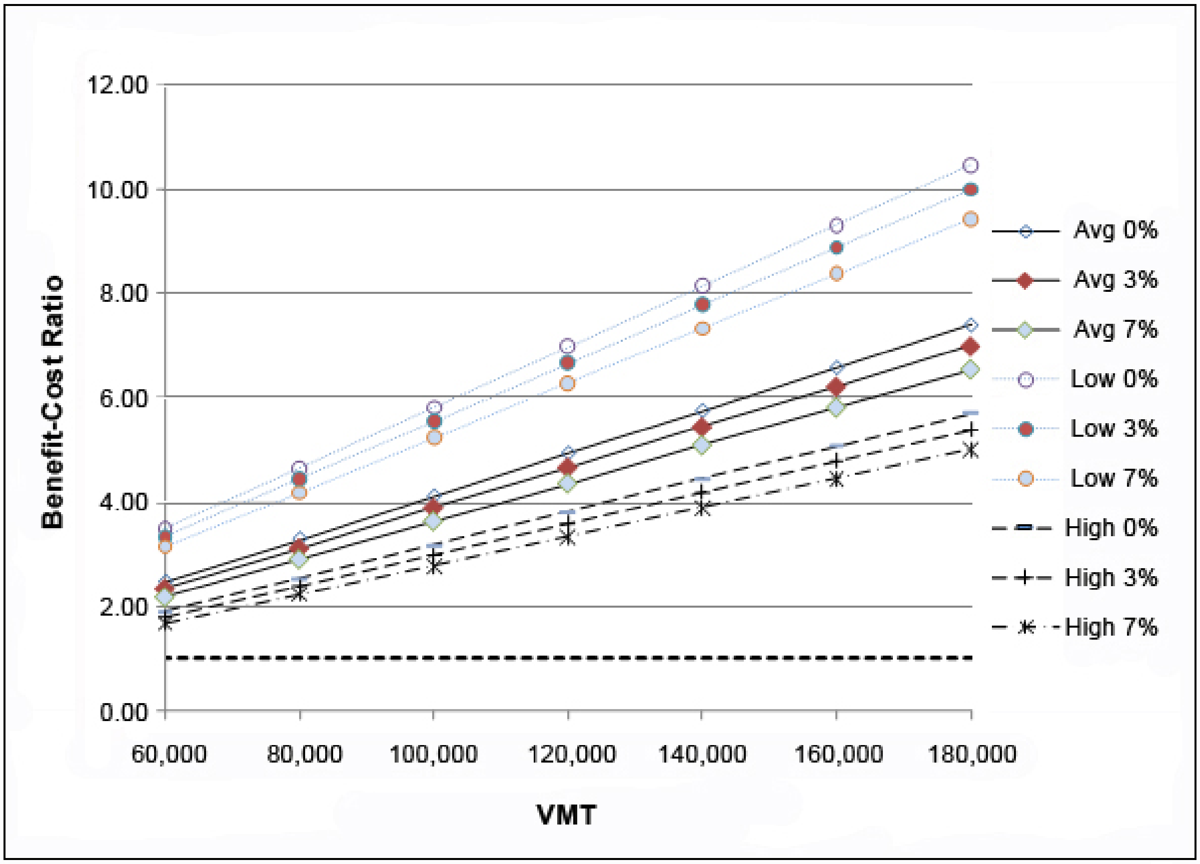

Figure 39. Line Graph. The Estimated Carrier BCR for Small Carriers With a $50,000 Deductible That Have Trucks With RSC by Initial Cost, Discount Rate, and VMT.

3.3.3 FCW Systems

Because the difference in FCW-related crash rates between trucks with FCW systems and trucks without FCW systems was not statistically significant, a benefit-cost analysis for FCW systems would not be meaningful or have practical value, and therefore, is not presented.

3.4 FOCUS GROUP DATA

3.4.1 Focus Group Demographics

Below are three tables that show descriptive data collected by the research team during the focus groups. A total of 12 focus groups (six with drivers and six with safety managers) were completed. Four LDW focus groups (two each with drivers and safety managers) were conducted at Carriers R and L, four FCW focus groups (two each with drivers and safety managers) were conducted at Carriers A and L, and four RSC focus groups were conducted at Carriers G and L (two each with drivers and safety managers). Table 58 shows the number of drivers and safety managers that participated in each focus group. As shown, a total of 9 drivers and 7 safety managers participated in the LDW focus groups, 10 drivers and 11 safety managers participated in the FCW focus groups, and 8 drivers and 11 safety managers participated in the RSC focus group.

Table 58. Number of Focus Group Participants by Carrier.

Carrier	Group	LDW	FCW	RSC	Total
Carrier A	Drivers	–	5	–	5
Carrier A	Safety Managers	–	7	–	7
Carrier L	Drivers	4	5	3	12
Carrier L	Safety Managers	4	4	3	11
Carrier R	Drivers	5	–	–	5
Carrier R	Safety Managers	3	–	–	3
Carrier G	Drivers	–	–	5	5
Carrier G	Safety Managers	–	–	8	8
TOTAL	N/A	16	21	19	56

Table 59 shows the demographic characteristics of the focus group participants, including: gender, age ranges, body mass index classification, marital status, and ethnicity. Note the following BMI Classes: <18.5 (Underweight), 18.5–24.9 (Normal Weight), 25.0–29.9 (Overweight), 30.0–34.9 (Class I Obesity), 35.0–39.9 (Class II Obesity), and ≥40.0 (Class III Obesity).

Table 59. Focus Group Participants' Demographics.

Carrier	Group	Gender M:F	Age (Yrs) *n*:Range	BMI Class *n*:Class	Marital Status *n*:Status	Ethnicity *n*:Ethnic Group
Carrier A (FCW)	Drivers	5:0	1:25–34 1:35–44 3:45–54	4:Overweight 1:Class II	1:Single 4:Married	4:Caucasian 1:Native American
Carrier A (FCW)	Safety Managers	6:1	1:25–34 3:35–44 2:45–54 1:55–64	N/A	N/A	7:Caucasian
Carrier L (FCW)	Drivers	5:0	1:25–34 1:35–44 3:45–54	1:Normal 1:Class I 1:Class II 1:Class III 1:NR*	2:Single 2:Married 1:Divorced	3:Caucasian 1:African American 1:Pacific Islander
Carrier L (FCW)	Safety Managers	3:1	3:35–44 1:45–54	N/A	N/A	4:Caucasian
Carrier L (LDW)	Drivers	4:0	4:35–44	1:Normal 1:Class I 2:Class II	1:Single 3:Married	2:Caucasian 2:African American
Carrier L (LDW)	Safety Managers	4:0	2:25–34 2:35–44	N/A	N/A	3:Caucasian 1:African American
Carrier R (LDW)	Drivers	5:0	1:35–44 3:45–54 1:55–64	2:Overweight 2:Class I 1:Class II	4:Married 1:Divorced	2:Caucasian 1:African American 1:Native American 1:NR
Carrier R (LDW)	Safety Managers	3:0	2:55–64 1:65–74	N/A	N/A	3:Caucasian
Carrier G (RCS)	Drivers	5:0	1:25–34 2:35–44 1:45–54 1:55–64	1:Overweight 3: Class I 1: Class II	1:Single 4:Married	3:Caucasian 2:African American
Carrier G (RCS)	Safety Managers	7:1	1:35–44 1:45–54 6:55–64	N/A	N/A	8:Caucasian
Carrier L (RSC)	Drivers	3:0	1:25–34 1:35–44 1:45–54	1:Normal 1:Overweight 1:Class I	1:Single 1:Married 1:Living With Significant Other-	3:Caucasian
Carrier L (RSC)	Safety Managers	2:1	1:25–34 1:35–44 1:45–54	N/A	N/A	3:Caucasian
Total	N/A	37:3	8:25–34 20:35–44 16:45–54 9:55–64 1:65–74	3:Normal 8:Overweight 8:Class I 5:Class II 1:Class III 1:NR 18:N/A	6:Single 18:Married 2:Divorced 1:Living With Significant Other 18:N/A	45:Caucasian 7:African American 2:Native American 1:Pacific Islander 1:NR

*NR = no response

Table 60 shows additional demographic characteristics of the focus group participants, including: education level, years driving a commercial motor vehicle, years employed with their current carrier, and years experience with the specific OBSS.

Table 60. Additional Focus Group Participants' Demographics.

Carrier	Group	Education Level *n*:Level	Years Driving CMV (Range)	Years with Carrier (Range)	Years Experience With OBSS (Range)
Carrier A (FCW)	Drivers	2:High School 1:Tech School 2:Some College	4 to 24	2 to 10	2 to 6 1:NR*
Carrier A (FCW)	Safety Managers	1:High School 3:Some College 1:Associate Deg 2:College Grad	N/A	4 to 20+	3 to 7
Carrier L (FCW)	Drivers	2:High School 1:Tech School 2:Some College	1 to 29	6 mo to 19 yrs	6 mo to 6 yrs
Carrier L (FCW)	Safety Managers	3:Some College 1:College Grad	N/A	5 to 12	5 to 7 1:NR
Carrier L (LDW)	Drivers	3:High School 1:Tech School	6 to 25	1 to 6	6 mo to 2 yrs
Carrier L (LDW)	Safety Managers	4:College Grad	N/A	4 to 14	3 1:NR
Carrier R (LDW)	Drivers	2:No High School 1:High School 1:Tech School 1:Some College	4 to 32	4 to 27	1 mo to 3 yrs
Carrier R (LDW)	Safety Managers	1:Tech School 1:Associate Deg 1:Professional Deg	N/A	4 to 36	4 to 5
Carrier G (RSC)	Drivers	3:High School 1:Tech School 1:Associate Deg	11 to 37	7 to 23	1 to 2
Carrier G (RSC)	Safety Managers	2:High School 1:Tech School 1:Some College 2:Associate Deg 1:College Grad 1:Master's Deg	N/A	2 to 27	0 to 3
Carrier L (RSC)	Drivers	3:High School-	9 mo to 10	9 mo to 3	9 mo to 3
Carrier L (RSC)	Safety Managers	1:High School 2:College Grad	N/A	4 to 23+	2 2:Not Sure
TOTAL	N/A	2:No High School 14:High School 7:Tech School 12:Some College 5:Associate Deg 8:College Grad 1:Master's Deg 1:Professional Deg	2:No High School 18:High School 7:Tech School 12:Some College 5:Associate Deg 10:College Grad 1:Master's Deg 1:Professional Deg	9 mo to 37	6 mo to 7 yrs

*NR = no response

3.4.2 Focus Group Content Analysis

Several themes regarding the carriers' OBSSs, including FCW, LDW, and RSC, were discussed during the focus group meetings with drivers and safety managers, including training, benefits of the systems, and drawbacks of the systems. Within each of these primary themes, several sub-themes were noted and discussed in each section. The research team organized participants' comments regarding each of these themes using content analyses.

3.4.2.1 LDW

Below are the content analysis results for the LDW focus groups. The results are presented for drivers first, followed by safety managers.

LDW Focus Groups with Drivers

Training: Drivers received most of their training for the LDW systems while driving their trucks on the road. Drivers recalled handouts posted around the truck terminal introducing and describing the LDW system. Drivers were also given a phone number to call that prompted them to a recorded message that provided information on the LDW system. This recording explained the circumstances in which the LDW system would activate, what to expect with the audible warnings, and disclosed there was no way to disengage the system. The recording also explained the LDW system enabled the driver to temporarily silence the audible alerts and the circumstances where it would be appropriate to do so (e.g., construction zones). Below are some driver comments regarding LDW training.

> ***Driver Comment**: I got my training when I [got in my truck], when I called up said "Look my speakers are making all kinds a racket." I didn't know what it was. I had no idea and that's when they explained it to me a little bit. But, there was no classroom on explaining it or whatever.*

> ***Driver Comment**: [NAME] also had a message on the phone system when you call in … explaining a lot of the lane departure system. So he explained on there that there would be audible sounds and that there was a delay. You can use the switch to delay the sound, you know.*

Benefits: Overall, the drivers felt the benefits of the LDW system outweighed the drawbacks. The LDW system reinforces good driving behavior and increases driver awareness. The drivers reported the LDW alerted them to fatigue and aroused them if they started to doze and drift outside their lane. The drivers noted the LDW system was also able to detect faded road lines the drivers had difficulty seeing. Another feature the drivers perceived as a benefit was the ability to deactivate the LDW system for limited periods of time (up to 15 minutes). Drivers liked this feature as the LDW system constantly sounded alerts when the lane marking were missing, such as construction zones. Drivers voiced strong opinions that LDW systems prevent crashes and increase safety.

Drivers were asked to give their overall satisfaction with the LDW and if they agreed the LDW was effective in improving safety on a 5-point Likert scale (e.g., *very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied*; and *strongly disagree, disagree, either agree nor disagree, agree, or strongly agree*). Overall, drivers were "satisfied" with LDW

(2 very unsatisfied; 1 neither unsatisfied/satisfied; 4 satisfied; 2 very satisfied) and "strongly agreed" that LDW was effective in improving safety (3 neither disagree/agree; 2 agree; 4 strongly agree). Below are some drivers' comments regarding the benefits of LDW.

> ***Driver Comment:*** *The first time … I guess my co-driver was kinda dozing off and the … went off and that kinda woke me up too so kinda came up and kinda see what was going on.*

> ***Driver Comment:*** *It's irritating. You know, you can press the button to turn [the LDW alert] off for awhile, but then it resets itself so the best way, you know, I was thinking that for you not to hear it, it'll make you more that you want to stay in between the lines so you don't have to hear it. So that actually builds your skills up when you're driving down the highway, it makes you actually want to focus to stay in your lane so you don't have to hear the noise.*

Disadvantages: Drivers reported several disadvantages in having the LDW systems in their trucks. They thought the audible alerts for the system were loud and annoying. They also disliked the numerous false alarms in construction zones and in road areas with old lane markings or residue, such as oil or pavement cracks, residing on the roadway. Drivers also noted the LDW system would not work properly on snow-covered roads, as the system could not detect the lane lines. Another disadvantage noted by drivers was that the LDW system would alert if the turn signal had been on for an extended time. This occurred mainly when a driver was sitting in traffic with their turn signal flashing and waiting to merge; when the driver found an opportunity to merge, the LDW would alert. Lastly, drivers thought the audible warning would trigger too late and alert them as they were already maneuvering across the lane line. Below are some driver comments regarding disadvantages of LDW.

> ***Driver Comment:*** *Ah, I don't have no problems with [the LDW system] either, except for construction zones. It's always going off. You know the lines are … they move all over the road. The lines aren't perfectly straight for the construction and it's just annoying going off a lot.*

> ***Driver Comment:*** *I mean, like there won't be no paint there. It's not a lane. It might pick up a seam. It could pick up that fresh oil from where they did, uh, and the light the sun is hitting it and putting a glare on it to make it stand out more.*

> ***Driver Comment:*** *… when my co-driver sideswiped a car … it was a little bit late then because she was right there so ...*

Driver Suggestions: Drivers suggested the LDW training could be improved by exposing the driver to the system before they drove with it for the first time on the road. One suggestion was to alert the system in a controlled environment under the supervision of a trainer. Some drivers also suggested the audible alert be introduced to drivers before they experience it on the roadway. Drivers also suggested improving the LDW system by equipping it with an audible alert that intensifies as the driver gradually approaches the lane line; although, drivers noted that this may not be feasible given the limited roadway width. Another suggestion from drivers was to vary the warning notification as they found the alert annoying. Drivers suggested that varying the sound would prevent them from habituating and ignoring the alert. Below are some comments regarding driver suggestions to improve LDW.

> ***Driver Comment:*** *It would have been nice to have the sound recorded and bring it to the room because like when I got in there I was like, you was trying to wonder how was it gonna sound.*

> ***Driver Comment:*** *Even I think something that intensifies as you go close to the line. You know, as you getting closer it kinda warn you before you get there. Cause a lot of time it's too late if you going down an embankment or something.*

LDW Focus Groups with Carrier Staff

Training: Carrier staff acknowledged that drivers received little training with the LDW system. One carrier noted that other than an instructional video, nothing else was offered to drivers; however, the carrier staff indicated the video was adequate for training purposes as it demonstrated the LDW system and how it operated. Staff from another carrier reported that drivers were briefed on the LDW system during driver orientation. They believed that more could be done to improve training, but had no specific ideas for improvement. Below are some safety manager comments regarding LDW training.

> ***Carrier Staff Comment:*** *As far as this system goes, the DVD is sufficient as far as training.*

> ***Carrier Staff Comment:*** *It's basically very simple. You cross the line and you get the sound on either side. Everybody knows that if you're on the highway and you drift over on the shoulder onto the rumble strips, it's basically the same sound. So it's really self-explanatory to the driver, they know what that sound is.*

Benefits: The LDW system assisted new drivers during training by providing drivers and trainers with immediate feedback if they unintentionally drifted outside the lane. The system continues to aid drivers after training by increasing driver awareness, encouraging turn-signal use, providing drivers with immediate feedback on their driving, and reinforcing good driving behavior. Carrier staff indicated that these behavioral benefits of the LDW system resulted in fewer motorist complaints. Although the LDW system was not designed to combat driver fatigue, carrier staff believed the LDW system alerted drivers to their fatigue by activating the system if they had an unintentional lane deviation. Carrier staff also noted that implementing the LDW systems in their trucks demonstrates the company's commitment to safety. Another benefit voiced by carrier staff was in regard to the financial benefits, such as the prevention of crashes; thereby reducing the company's crash-related insurance costs and liability.

Carrier staff members were asked to give their overall satisfaction with the LDW and if they agreed the LDW was effective in improving safety on a 5-point Likert scale (e.g., *very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied*; and *strongly disagree, disagree, either agree nor disagree, agree, or strongly agree*). Overall, carrier staff were "satisfied" with LDW (7 satisfied) and "strongly agreed" that LDW was effective in improving safety (3 agree; 4 strongly agree). Below are some safety manager comments regarding the LDW benefits.

Carrier Staff Comment: *Well, it could be an early warning system that you're getting tired, if you start hearing this thing repeatedly, because that's one of the signs of getting tired because you keep drifting off the road*

Carrier Staff Comment: *It reinforces to the driver our commitment to safety. We're embracing the newest technology out there. We're investing money in that, it gives us added opportunities to talk about it, the capabilities and the perils that are out there, so that's a benefit.*

Carrier Staff Comment: *I just think a lot of the technology that we've invested in is not only to help the drivers but to help our company stay viable, you know. When it comes to liability when there is a, you know, an accident or something. And a lot of the technology we have is, you know helpful in maybe mitigating or settling that stuff and proving that we weren't at fault. So, I mean I think the technology we have is very important in that respect.*

Disadvantages: Carrier staff noted that a disadvantage in implementing the LDW systems in their trucks was the rapid improvements in technology that can make their systems obsolete. Carrier staff were also concerned that drivers may become dependent on the LDW systems and rely on them as safeguards while practicing unsafe driving behavior, such as driving while fatigued. Carrier staff suggested that over time, drivers may habituate to the alert, especially if they have experienced frequent false alerts or system malfunctions. Carrier staff also reported numerous complaints from drivers regarding the LDW systems, such as annoying and frequent false alerts on roads with old or faded lane lines or markings. Another disadvantage cited by staff was that the LDW alert could be distracting to drivers, thereby hindering safety. Carrier staff also believed that drivers thought the LDW was an invasion of their privacy and, hence, hard for them to embrace. Carrier staff indicated the LDW system was not functional on unmarked roads or in foggy conditions. Another disadvantage of the LDW systems cited by carrier staff was the lack of feedback from the system regarding maintenance. Thus, carrier staff members are reliant on drivers to provide this information (which they believed would be unlikely without a prompt). Below are some safety manager comments regarding disadvantages of LDW.

Carrier Staff Comment: *It's just that old mentality. When you're driving down the street and you hear somebody honk their horn, what's the first thing you do? You brake, you turn, you look, well you know, no we're not paying attention to what's going on because you got this thing that could be a malfunction going off or if you haven't heard it in three days and it bangs on you, it kinda startle you or whatever the case may be.*

Carrier Staff Comment: *It drives them absolutely up the wall. I mean, they'll shut it down and say "I can't drive this." I mean, it's like if you had an alarm clock going off you know in your car with you the entire drive. But your drive isn't 30 minutes to work, it's 1,400 miles. You know, it's, I mean it's. They become extremely frustrated.*

Carrier Staff Comment: *They should not rely upon the system. If you're really tired and you're on the road and you want to get somewhere, we've all been there*

> *where we've been driving all night long trying to get someplace. And you're trying everything from chewing ice to drinking coffee, etc. Then if you got comfortable, you say, well if I do drift off a little bit, this thing's going to wake me up, that would be dangerous.*
>
> ***Carrier Staff Comment:*** *But they also see this as an infringement on their rights, this is big brother, and I'm sure you heard that. They don't like new technology. Some of it is because they don't understand it. We don't talk about the compliance side of it, we talk about the purpose of, and what it's designed for and how it's going to help them. None of them embrace it.*

Carrier Staff Suggestions: Carrier staff indicated several ways in which the LDW system could be improved. Currently, staff members receive no feedback on the data generated from the LDW systems; however, staff felt this information could serve as a red flag for drivers who had a significant number of alerts. Carrier staff noted the ability of the LDW system to distinguish the edges of roads without lines should be improved. If the system could detect the edge of the road by detecting pavement versus grass or dirt, it would alert drivers during an unintentional lane departure on roads without painted road markings.

3.4.2.2 Roll Stability Control

Below are the content analysis results for the RSC focus groups. The results are presented for drivers first, followed by safety managers.

Roll Stability Control Focus Groups with Drivers

Training: Drivers reported the only training they received on the RSC system was watching a video that demonstrated how the RSC system worked in different conditions and scenarios. The video demonstrated how the RSC system worked to stabilize the truck and showed scenarios where trucks without the systems would rollover. Below is a driver comment regarding RSC training:

> ***Driver Comment:*** *Yeah, basically all it was uh, had a video to watch. It showed different, different uh, on ice and snow and then just on regular pavement you know what the system could prevent. They had … trailers that had actually training wheels you could say on them. And they went through the course and if they didn't have the wheels it'd turn over. And then when they went back and showed it with the stability system, that they never did tip, touch the ground.*

Benefits: Drivers reported the RSC system was beneficial and they liked having it on their trucks. Drivers indicated the RSC system increased their situational awareness, making them more cognizant of their driving behavior. The system also aids the driver's judgment when calculating speed into turns. Drivers noted the RSC alerted them to their own fatigue (e.g., the RSC system may engage if the driver makes a poor driving decision due to fatigue, such as entering a curve too fast). Drivers believed the RSC system increased safety by preventing rollovers. Drivers indicated that a rollover crash can cause traffic delays or extensive damage that can bring negative attention to the carrier. Additionally, the driver felt that RSC can save the carrier money that would have been spent on the rollover crash. Drivers also believed that fewer rollovers improved driver retention, as drivers can be fired if they cause a crash. Drivers felt pride that their fleets have the RSC systems in place and a sense of superiority over other fleets without these systems. Drivers also noted that having the RSC systems on their trucks gave them "piece of mind" and made them feel safe when riding with inexperienced trainees.

Drivers were asked to give their overall satisfaction with RSC and if they agreed the RSC was effective in improving safety on a 5-point Likert scale (e.g., *very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied*; and *strongly disagree, disagree, either agree nor disagree, agree, or strongly agree*). Overall, drivers were "satisfied" with RSC (5 satisfied; 3 very satisfied) and "strongly agreed" that RSC was effective in improving safety (6 agree; 2 strongly agree). Below are some driver comments regarding RSC benefits.

> ***Driver Comment:*** *Um, so it'll get your attention. Uh, you know, it'll actually wake you up if you're, if you're a little drowsy it's like "What was that," you know.*

> ***Driver Comment:*** *Yeah, because when we first got this on the truck, I was getting it to activate quite a bit. And maybe it's made me a more cautious driver, you know? Or maybe, they tweaked the system where it's not as sensitive, you know where it takes a lot more to activate it versus before. Or, maybe I'm just going into turns a little slower than I was before. I'm not sure.*

> ***Driver Comment:*** *I think anything you can do to, you know, to be a little cautious and uh, you know I don't really know how the trailer is loaded. I can look at the trailer documents and it'll say: 100% loaded or it'll say 50% loaded. So if it says 100% loaded and it's a heavy trailer and if I've got two of them together I think it's more prone to roll over and, but you know, if it's 50% loaded I don't know if it's loaded high or if it's just, you know, if it's loaded high in the front, which would cause it to roll over easier or if it's loaded along the floor and the top of the trailer is empty. So, I don't really see the trailers once they close out. So, I think the module is picking up the roll of the tractor which is affected by the weight of the freight in the trailer plus the height of the freight in the trailer. So, it probably is a better indicator of vehicle roll than me sitting in the cab waiting for the truck to roll.*

Disadvantages: Drivers indicated the RSC system does not have an indicator to notify drivers if the system is broken or functioning improperly; thus, drivers were unaware if the system needed maintenance. (This is a misperception because the traction control light serves double-duty as a stability control fault light.) Some drivers thought it was possible to become overly reliant on the RSC system (e.g., if the system failed to work, a crash could result). Drivers also disliked the loss of authority over their truck and felt the sensitivity of the system was too conservative. Drivers also expressed concern regarding the RSC system activating in dangerous conditions, such as rain or ice (as the driver is not able to override the actions of the system). Drivers expressed concern regarding how the RSC system worked with different brake settings and with trailers that have ABS versus those that do not have ABS. Below are some driver comments regarding the disadvantages of RSC.

__Driver Comment:__ You don't really know if the system is working or not until you actually get into a position where you overdrive the truck. And then if it's not working you still won't know, 'cause it won't advise you.

__Driver Comment:__ If you're going into a situation where a lot of times the roads may normally be great, but you'll lean into a turn or a sharp ramp and it may be under an underpass and the temperature is below freezing and you got that little bitty stretch right there, maybe just 20 or 30 feet, that's just black ice. And, here again you know, this, you know devil's advocate here but, if everything were to go just wrong and that system were to apply when you're on that little section, and here again that trailer didn't have ABS, would it, the possibility is there for that system to, you know that rear trailer, or that converter gear to kick out and lock up on that small section of ice.

__Driver Comment:__ I kinda think that it activates a little too soon. 'Cause it, it'll throw you off. I mean, it'll catch you off guard and it'll throw you off and uh. It's just a bad feeling. I mean seriously.

<u>Driver Suggestions:</u> Drivers had several suggestions on how to improve RSC training. They felt it was important for drivers to receive more information about the RSC system, such system functionality and how the systems are installed on their trucks. Drivers indicated they did not fully understand how the RSC system worked and suggested more training to explain the engineering and mechanics of the system. They also suggested that experiencing the RSC system activate in a simulator or closed course environment would acclimate them to the system. Below are some comments regarding driver suggestions to improve RSC.

***Driver Comment**: They may have something set up where a driver can experience it before they're actually driving the truck, you know, in the situation, maybe something on the yard or something like that. Like set up in the video. So you can experience the feel of everything so it won't, you won't be shocked whenever you first feel it.*

***Driver Comment**: Those simulators are really expensive. But it would be good if the companies could, maybe not buy one, but if they could just rent one for awhile and have it set up for a couple days at decent terminals.*

3.4.2.3 Roll Stability Control Focus Groups with Staff

<u>Training:</u> Some carrier staff indicated the RSC training provided to drivers was insufficient. One group believed that drivers were not coming to them with questions regarding the RSC; thus, training must be sufficient. After the RSC systems were installed on the trucks, some drivers attended road driver equipment sessions where the RSC system was described; these drivers were expected to inform other drivers about the RSC system. Below is a safety manager comment regarding RSC training.

__Carrier Staff Comment:__ We were reliant on [driver attendees of road driver equipment sessions], to get the word out to the other drivers opposed to including

> *it in the monthly safety copy. And I think that's probably somewhat where we failed in terms of every employee was aware of it.*

Benefits: Carrier staff reported several benefits inhaving the RSC system installed on their trucks. They felt the RSC system benefited company drivers, the carrier, and the motoring public. Staff believed the RSC system improved drivers' confidence in their driving ability and improved their drivers' skills. Additionally, carrier staff liked the ability of the RSC system to automatically engage rather than relying on driver input. Carrier staff also believed the RSC system reduced equipment wear, including brakes and tires. However, the primary benefit of the RSC system was the reduction in crashes (including reduced freight damage, liability, and damage to personal property). Carrier staff also reported that fewer crashes result in fewer injuries and fatalities. Carrier staff also noted that RSC systems are an attractive selling point for potential drivers and their families who are concerned about driver safety, as well as customers who expect their freight to arrive intact.

Carrier staff members were asked to give their overall satisfaction with the RSC and if they agreed the RSC was effective in improving safety on a 5-point Likert scale (e.g., *very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied*; and *strongly disagree*, *disagree, either agree nor disagree, agree, or strongly agree*). Overall, carrier staff were "satisfied" with RSC (8 satisfied; 3 very satisfied) and "agreed" that RSC was effective in improving safety (9 agree; 2 strongly agree). Below are some carrier staff comments regarding RSC benefits.

> ***Carrier Staff Comment:*** *Well yeah, you might save one of your driver's lives. That's where the real economic impact comes from is injury. You know, death and injury. And uh, uh, you know it just snowballs from there. Anything we can do to prevent one of our drivers from getting injured or killed or killing someone else.*

> ***Carrier Staff Comment:*** *… if we prevent one rollover, I mean there's a cost savings to the company. There's also the savings of getting somebody hurt or not getting somebody hurt in that accident. All-in-all it's a good system and uh, the company benefits cost-wise because 10 rollovers is a lot of dollars for us versus no rollovers.*

Disadvantages: Carrier staff believed the costs incurred by the carrier-wide implementation of these systems, including training the drivers and maintaining, repairing, and replacing the systems and equipment, was a significant investment. Carrier staff indicated that an ongoing challenge is gaining driver acceptance of the RSC system. Carrier staff reported they received numerous complaints from drivers about lack of control once the RSC system was activated. Carrier staff also voiced concern that drivers may become overly reliant on the system and not maintain their awareness. Carrier staff were concerned that drivers may blame the RSC system for their involvement in a crash rather than taking personal responsibility for involvement in the crash. Below are some safety manager comments regarding RSC disadvantages.

> ***Carrier Staff Comment:*** *Well, you can't fix stupid. I mean if you go, you know if you're gonna go into a curve at 60 mile an hour it can only do so much. You're just gonna lose it that's it.*

> ***Carrier Staff Comment:*** *I think it's the driver feeling he doesn't have control. And then he tries to control it as if he would and it doesn't respond and creates a panic on him at that part.*
>
> ***Carrier Staff Comment:*** *But that's another thing. I mean, in the future as we have more and more systems I think it's gonna become possible that the driver will blame failure or an accident on the system. But, fortunately, that's why I'm pushing 'em to record more and more information and also the government is pushing them to do so. That way if there is an accident they can reconstruct it, you know, digitally.*

Carrier Staff Suggestions: Carrier staff indicated that RSC training could be improved by informing drivers how the system functions. Staff believed that if drivers realized the RSC system was installed to keep them safe, they would be more likely to accept and embrace the technology. Staff also suggested that drivers may benefit from experiencing the RSC system first hand via a simulator or in a controlled environment. Some staff indicated the RSC manufacturers host demos throughout the year, drivers could attend these demos to learn more about the system.

3.4.2.4 FCW

Below are the content analysis results for the FCW focus groups. The results are presented for drivers first, followed by safety managers. Note that the most remarks made about FCW had to do with CMBS comments, perhaps, due to strong driver feelings over loss of authority or control in situations requiring application of vehicle's foundation brakes.

FCW Focus Groups with Drivers

Training: The FCW training received by drivers included watching a manufacturer- and/or carrier-made video during a safety meeting. The video demonstrated the components and operations of the FCW system and explained to drivers how to properly use these systems while driving. In addition to the video, drivers noted that carrier personnel were always available to address any questions or problems with the FCW system. Some drivers reported that the training they received was good, but that it could be improved by allowing the driver to experience the FCW and how it activates prior to driving a truck installed with the system. Other drivers felt that more classroom education was needed to discuss differences between FCW systems and how drivers should react to these systems.

Benefits: Drivers expressed a number of benefits with FCW systems, such as improved following distance. Drivers also stated the FCW helped alert them to their fatigue. The FCW systems aided drivers in conditions where visibility was poor, such as heavy rain, fog, or poor lighting. This included detecting inconspicuous vehicles without lights and vehicles parked on the shoulder of the road. Drivers also noted the financial benefits of the FCW systems for the company (which in turn helps to keep more money in drivers' pockets). Drivers discussed one type of FCW system, CMBS, which not only alerts the driver to vehicles and objects in the forward roadway, but will intervene and activate the truck's brakes should the driver not react quickly enough. Some drivers liked this feature of the CMBS, as it provided the driver with better reaction time. The braking feature of the CMBS prevents crashes, but also reduces the severity of crashes by reducing the speed of the truck prior to impact. The CMBS also informs drivers of the speed and distance to lead vehicles, thereby allowing drivers to make safe driving decisions. Drivers also appreciated the CMBS system did not detect animals in the road (as it is safer to hit the animal rather than attempt an evasive maneuver). Some drivers had experience with the FCW system that alerts the driver to vehicles and objects in the forward roadway but did not provide information on speed or distance of lead vehicles (nor will it engage the brakes). Drivers reported that they enjoyed the ability to adjust the sensitivity and volume of the alerts on the FCW system, which was not possible with the CMBS.

Drivers were asked to give their overall satisfaction with the FCW and if they agreed the FCW was effective in improving safety on a 5-point Likert scale (e.g., *very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied*; and *strongly disagree, disagree, either agree nor disagree, agree, or strongly agree*). Overall, drivers were "satisfied" with FCW (1 neither unsatisfied/satisfied; 7 satisfied; 2 very satisfied) and "strongly agreed" that FCW was effective in improving safety (3 agree; 7 strongly agree). Below are some driver comments on the benefits of FCW.

> ***Driver Comment:*** *FCW has gotten me out of stuff. Like I was driving one night and it was foggy … Couldn't see 2 inches in front of my face and all of the sudden it lit up and beeped twice and I got out of it. And as I got there … traffic was just dead stopped.*

> ***Driver Comment:*** *... I love the fact that it keeps my automatic speed behind somebody. I love the fact that it tells me what the driver in front of me is doing, his speed, if I have the ability to pass ... It has prevented me from about three accidents, one just last week. I had a car cut me off and the CMBS system dynamited all 18 wheels on my truck and prevented me from hitting him.*

> ***Driver Comment:*** *I've seen trucks that had it, I've seen trucks that have not had it. In the way of an actual collision, with these CMBS, the impact is much less. They're hitting them at 35/40 mi/h instead of 65/70 mi/h. It's allowing the drivers to keep control of their tractor trailer. It's allowing people to get hit at a reduced speed. Instead of the truck jumping up and rolling them over, it's hit at a much reduced speed. We had a driver with CMBS on his truck, he was on cruise control when he hit the other car. It did not stop him but the people came out of the hospital 3 days later. It had slowed him down fast enough so that when he made contact, instead of him rolling over them, the momentum spun the car off after impact.*

Disadvantages: Drivers also expressed several disadvantages with the FCW systems, such as the CMBS does not allow drivers to adjust the volume or sound of the alert. Drivers from one carrier discussed how the brake lights on the trucks do not activate when the CMBS engages. Drivers perceived this as a significant safety issue for rear-end collisions; however, another group of drivers disliked that the CMBS does engage the brake lights when slowing the truck by a few miles per hour. Drivers felt that engaging the brake lights with minimal decreases in speed was also a safety issue, as it might cause overreactions or unnecessary maneuvers from following vehicles. Drivers also voiced that the CMBS would brake too hard at times, resulting in unnecessary nose dives. For example, when a car merges into the truck's lane (in front of the truck), the CMBS brakes quickly. The driver's lack of control over his or her truck with the CMBS was another disadvantage expressed by drivers as they felt that in some situations they know how to react more appropriately than does the CMBS. Drivers also expressed concern with regard to their lack of authority in poor weather conditions, such as rain or ice. The CMBS would not recognize an unsafe road condition; thus, may brake too hard while on poor road conditions resulting in loss of control. Drivers stated that another drawback was the continuous disabling of their trucks' cruise control, which can happen when the radar system is not aligned with the CMBS. It was frustrating for drivers to lose authority of the cruise control, as it assists drivers on long trips and helps with fuel efficiency and costs. Drivers indicated the FCW system had frequent false alerts from detecting overpasses, guardrails, and vehicles parked on the side of the road. Below are some driver comments regarding disadvantages of the FCW.

> ***Driver Comment:*** *I'm nervous you know when you, like he said, I mean [the truck] is 80,000 pounds; you don't want it being out of your control.*

> ***Driver Comment:*** *But you know they're going and like he said, a car merging on but you already can tell they're getting on it to get on down the road. The CMBS will misinterpret what is going on and all you've got to do is just have your foot ready because you can tell just as soon as it starts you know backing you off or shutting you down and then let it go on, let the car go on and it senses 'oh, okay' then it will go back to what it's doing.*

> ***Driver Comment:*** *For me about 4 months now and I've worked with both [FCW] systems. The only complaint I've got about the system-it's calibrations on it. You'll be going straight down the road it'll pick up a parked car 25 feet off the side of the road and nose dive you.*

Driver Suggestions: Drivers felt the training they received on the FCW systems could be improved. They suggested that a classroom discussion on the different types of FCW systems would be useful, including how they work, their capabilities and limitations, etc. Another suggestion to improve training was to allow drivers the opportunity to gain hands-on experience with the systems, either in a simulator or in a controlled environment (such as a closed driving course), prior to experiencing the systems on the road. Drivers felt this kind of training would better prepare them when the system activates, rather than experiencing the alert for the first time on the roadways. Drivers suggested the FCW system could be improved by making the sensor detect only vehicles and objects in front of the driver and in the same lane as the truck (thereby reducing the false alarms). Drivers also recommended that the FCW system include a rear-end detection feature to alert them to tailgating vehicles. The drivers who reported the CMBS did not engage the brake lights when activated, suggested the CMBS be linked with the truck's braking system so that the truck's brake lights engage when the CMBS engages. Additionally, drivers suggested that engaging only the trailer brakes, rather than the tractor brakes, when the CMBS is activated would lead to fewer nose dive situations. They also recommended the CMBS system be improved to be able to distinguish poor road conditions, such as rain or snow. Drivers suggested the FCW system should automatically deactivate when the truck is parked and idling so the FCW system does not alert to passing cars while the truck is parked. Below are some comments regarding driver suggestions to improve FCW.

Driver Comment: *... they always say worry about who's in front of you or beside you but not behind you. So if someone is tailgating you, I either slow down and make them pass me or I'll pull to the shoulder and tell them to go. But there is a lot of times a car or motorcycle will get there and you can't see them! You don't know they're there and you go to brake down and they're right in the back of your trailer. But if that would come on and let you know that they're too close, that would be great!*

Driver Comment*: Mine picks up overpasses, birds flying across, phantom signals. And what's bad is if you're parked and asleep in your bunk. You can't turn the FCW off, so every time a car passes in front of your truck, beep beep beep!! That's one that should be up there. If you're parked, the sensor should automatically deactivate.*

FCW Focus Groups with Staff

Training: Carrier staff indicated that company drivers receive education and training on the FCW systems through a variety of media. Drivers watch a video created by the manufacturer and, in some cases, additional materials (which describe the FCW system and its features) from the carrier are included. Drivers are also educated on the FCW technology in a classroom environment and are given a followup questionnaire to evaluate what they learned. The training crew is available for one-on-one discussions with drivers if they have questions regarding the FCW system. Drivers also participate in a yearly refresher training course to remind them how to safely and properly use the FCW equipment on their trucks. Below are some safety manager comments regarding FCW training.

Carrier Staff Comment*: Some of the training has little questionnaires after tests. Just to see if they caught, what they've looked at, what they've read. And the training crew they're there the whole time so if there's more questions or things they don't understand they can help them. We have specific training, for the new trucks. So if a driver changes from an old truck to the newer version then they go in there for the class …*

Carrier Staff Comment: *Well, I think we have academics and then we have the hands on. I mean, and followups, involved with a simulator.*

Benefits: The FCW systems provide an early warning of potential collisions and promote better driving habits by keeping drivers alert and aware of their following distance and tailgating. Staff members believed that drivers are unable to drive aggressively with these systems and less likely to be fatigued while driving. They liked being able to access the data from the FCW system, including the truck's following distance and speed. This information is used to alert staff to drivers who may need additional training. Carrier staff reported the FCW systems save money by reducing wear on the trucks and preventing crashes (which, in turn, reduces down time, repairs, and insurance costs). Having these systems installed on trucks promotes a positive public image for the carrier as it emphasizes their commitment to safety. Carrier staff noted that a CMBS is able to react faster than the driver in certain situations; thereby slowing the truck and avoiding a crash without driver intervention.

Carrier staff were asked to give their overall satisfaction with the FCW and if they agreed the FCW was effective in improving safety on a 5-point Likert scale (e.g., *very unsatisfied, unsatisfied, neither satisfied nor unsatisfied, satisfied, or very satisfied*; and *strongly disagree, disagree, either agree nor disagree, agree, or strongly agree*). Overall, carrier staff were "satisfied" and "very satisfied" with FCW (6 satisfied; 6 very satisfied) and "strongly agreed" that FCW was effective in improving safety (3 agree; 8 strongly agree). Below is a safety manager comment regarding the benefits of FCW.

> ***Carrier Staff Comment****: It definitely will make your driving habits better … it will control your speed at a center point, you know, on your following distance. Talking with older drivers, they've had to change their way of driving from being, you know, aggressive, to pulling back it seems like. And uh, I think now since it's out there that they appreciate it more and seen what they was doing really. So it's definitely helped [the carrier] as a whole.*

Disadvantages: A number of disadvantages voiced by safety managers concerned the initial implementation of the FCW systems on the trucks rather than the functionality of the FCW systems. The initial monetary and time investment to purchase and install the FCW systems and properly train drivers was identified as a disadvantage in implementing the FCW systems. The carrier staff perceived retrofitting the systems on older trucks and system repairs as disadvantages. Carrier staff voiced concerns regarding the obsolescence of the FCW technologies, as these systems become quickly outdated. Other disadvantages noted by carrier staff were the costly repairs and limited repair options (only one main service and repair center). Another disadvantage perceived by carrier staff were drivers becoming reliant on the systems and not paying attention to the road. They also suggested that drivers may become habituate to the audible warnings over time. Some carrier staff believed the voluminous amount of data was difficult to comprehend and piece together in a cohesive picture, and found it inconvenient the data could not be downloaded wirelessly. Carrier staff also reported driver complaints that the FCW systems detected overpasses and bridges. Carrier staff also voiced their preference for the active CMBS over the passive FCW system. Below are some safety manager comments regarding disadvantages of FCW.

> ***Carrier Staff Comment:*** *Sometimes people give over to technology. You still have to preach common sense. You're still the driver, still pay attention to what you're doing, you need to maintain your box. This is a fail-safe. If something happens or you're not as alert as you should have been or somebody cuts in front or something happens, [the FCW system] is going to put your brakes on. But you are really the person who needs to take care of the driving. Because you're the human brain to react and see things before the computer can or does. This is the last minute, person that gets too close, Bam, it's there to help them.*

> ***Carrier Staff Comment:*** *I wanted to move to an active system, is because of complacency and getting used to it … I talked to guys that um, "did you not hear the FCW?" "Ah, I didn't hear it." But they've been driving one of those trucks equipped with it for three or four years. And uh, and you just have to get past that. I don't think, and I'm not here to slam them, it's about, it needs to be an active system, it's gotta be able to control the driver somehow. Not the driver, but the*

truck. You gotta get his attention and if he's zoned out he's never gonna hear anything. He's never gonna hear anything, so it has to be an active system.

<u>Carrier Staff Suggestions:</u> Carrier staff voiced several suggestions to improve the FCW training, as well as recommendations for improving the systems. Carrier staff suggested the entire company should participate in the FCW training, provide more one-on-one training with drivers to detail how the systems work, and use videos and/or driver testimonials to demonstrate to novice drivers how the FCW systems have aided other drivers. Carrier staff felt the calibration of the FCW unit should be improved to reduce the number of false alarms. As staff had no way of knowing if a driver's FCW was malfunctioning (unless informed by the driver), they would also like to receive more direct feedback from the FCW systems rather than relying on drivers. Carrier staff suggested some sort of notification, via email or the Qualcomm system, to alert them to FCW problems. Additionally, staff thought it would be helpful if the data from the system could be uploaded and sent wirelessly so they could more easily monitor their drivers. Lastly, carrier staff suggested integrating OBSSs into one system so that carriers may choose options from one OBSS and have them easily integrated with options from another OBSS. Below are safety manager comments regarding their suggestions to improve FCW.

> ***Carrier Staff Comment:*** *Yeah, test, test and don't just put it on. You get guys that you know are … going to tell you the good the bad and the ugly because that's what you need to hear. Uh, and then once the very first one or two of them have a situation you start broadcasting, getting it out there, let those guys do the testimonial for you that we talked about. If you just took this to a company and you just put it on, and you just walked out and told the drivers "Here it is, you're gonna use it," you're gonna have so much backlash.*

> ***Carrier Staff Comment:*** *The problem uh, with the guys been using it awhile and hasn't been very experienced, a situation that helped him … it won't report it to you that it's broke, cause he feels he doesn't need it…You know, a warning system that let the carrier know when it's not operating properly should be a design that they need to look into … You know, it's very important that you got the technology, you know, to use it. And then, if it's not working, the carrier needs to know about it.*

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4. DISCUSSION

4.1 SUMMARY

The current study assessed the safety benefits of three different OBSSs installed on Class 7 and 8 trucks as they operated during normal revenue-producing deliveries. Whereas other studies assessed the safety benefits of these systems in cars,[21,32,33,34,42,60] using simulations/models,[2,5,8,10,35] or crash rates obtained from large national or State crash databases,[3,6,7,9,36] the current study used real-world data collected from carriers to determine the efficacy of these OBSSs. Crash data from 14 carriers representing small, medium, and large carriers hauling a variety of commodities were used. The data from these carriers included a total of 88,112 crash records and 151,624 truck-years that traveled 13,065 MVMT. Of these 88,112 crashes, only a small percentage were crashes that could have been mitigated or prevented by LDW (n = 2,404), RSC (n = 665), and FCW (n = 1,194). These data were collected over a 3-year period from 2007 to 2009 (and in 2010 with one carrier).

The approach used in this research went far beyond any previous study in this domain. First, the current study used data collected directly from participating carriers; thus, the resultant dataset used in the analyses contains a broad spectrum of crashes (many of these crashes were not reported to State or Federal agencies). Second, the research team collected detailed information on the trucks and the safety management techniques at the participating carriers; thereby allowing 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. Last, the research team reviewed each crash file to determine if the specific OBSS would have mitigated or prevented the crash.

4.2 CONCLUSIONS

4.2.1 OBSS Effectiveness and Benefit-Cost in Heavy Trucks

The primary safety analysis conducted in this study focused on the potential reduction in truck crashes with one of three OBSSs. The data used in the study were divided into two cohorts: trucks with an OBSS and trucks without an OBSS. The crash data were also arranged into two groups: crashes that were OBSS-related, and crashes that were not OBSS-related. The safety analyses included a Poisson GEE model to accommodate the potential overdispersion effect. The results across analyses indicated a strong, positive safety benefit for LDW and RSC.

In the current study the overall crash rate varied from 4.5 to 7.0 crashes per MVMT (depending on the OBSS cohort). This crash rate was far higher than the large truck crash rate reported in the 2008 Traffic Safety Facts (1.36 crashes per MVMT). This does not reflect unsafe carriers, but rather a dataset that included a greater number and diversity of crashes compared to national crash datasets derived from police accident reports and other sources. Most of these crashes were lower severity crashes that were not reported via police accident reports; thus, contributing to the higher overall crash rate compared to GES. The research team believes the current carrier-collected dataset, though not representative of the overall motor carrier industry, is more representative of the motor carrier crash picture than reported in GES.

The trucks with LDW had an LDW-related crash rate (per MVMT) that was significantly lower than the rate for trucks without LDW (i.e., the CRR in the non-LDW cohort was 1.92 times greater than in the LDW cohort). This CRR translates into a 47.8-percent crash rate reduction per MVMT in RSC-related crashes with RSC. This reduction was on the high-end of the range (23 percent to 50 percent) predicted in other research studies that have assessed the efficacy of LDW systems.[2,3,4,5,6] However, these studies reported reductions in the number of LDW-related crashes and not the CRR. Moreover, the effects of LDW on LDW-related crashes were independent of the other OBSSs (i.e., FCW and RSC did not have a significant effect on LDW-related crashes).

The BCA clearly showed the benefits of LDW outweighed the costs. It was estimated (assuming an average initial cost for LDW and 0 percent discount) that carriers with LDW would experience a BCR of 14.86–4.95, an NPV of $3,034–$10,636, and a payback period of 12–4 months (from 60,000 to 180,000 VMT/year), and society would experience a BCR of 5.71–1.9, an NPV of $1,008–$5,260, and a payback period of 32 to 11 months (from 60,000 to 180,000 VMT/year). The BCAs also showed equally impressive results for varying discount rates, initial costs for LDW, financing, extended service life, small carriers, and high-value cargo. Houser et al.,[3] estimated the carrier BCR of trucks with LDW to be 6.55–1.37 with a 3 percent discount (depending on VMT). The carrier BCR in the current study was much higher than reported in Houser et al.[3] The difference in the LDW-related crash rate between the non-LDW and LDW cohorts in the current study was more than twice as effective as reported in Houser (0.093 versus a high of 0.037, respectively).

Abele et al.,[2] and Visvikis et al.,[6] estimated the BCR using mandatory LDW deployment and found BCRs of 2.0 and 0.18–6.56, respectively. The current study found that mandatory LDW deployment over a 20-year period with replacement of LDW every 5 and 10 years would result in BCRs of 1.97 and 3.40, respectively. The reason for the discordance in the BCR for mandatory LDW deployment in the current study and Abele et al.,[2] and Visvikis et al.,[6] was related to the severity of the LDW-related crashes. The current study found that the proportion of LDW-related crashes that could have been prevented or mitigated by LDW was more likely to be lower severity PDO crashes than was found in the GES. Only 79.8 percent of the LDW-related crashes in the GES dataset were PDO (using a filtering process similar to that employed in the current study); however, 91.9 percent of the LDW-related crashes in the current dataset were PDO crashes. This means the BCAs in the current study were estimated using less severe LDW-related crashes than those found in GES. This had a negative effect on the BCA by reducing the estimated benefits. However, the research team does not view this as a limitation, but as a more accurate and representative assessment of the real-world efficacy of LDW.

A similar relationship was found in RSC. Trucks with RSC had an RSC-related crash rate (per MVMT) that was significantly lower than trucks without RSC (i.e., the CRR in the non-RSC cohort was 1.555 times greater than the RSC cohort). This CRR translates into a 35.7-percent crash rate reduction per MVMT in RSC-related crashes with RSC. This 35.7-percent reduction is on the low end of the range (26 percent–64 percent) predicted in other research studies that have assessed the efficacy of RSC systems.[7,8,9] As indicated above, these studies reported reductions in the number of RSC-related crashes and not the CRR. Moreover, the effects of RSC on RSC-related crashes were independent of the other OBSSs (i.e., FCW and LDW did not have a significant effect on RSC-related crashes).

The BCA clearly showed that the benefits of RSC outweighed the costs. It was estimated (assuming an average initial cost for RSC, 0 percent discount, and no financing) that carriers with RSC would experience a BCR of 12.50–4.17, an NPV of $1,401–$5,088, and a payback period of 14–5 months (more than 60,000–180,000 VMT/year), and society would experience a BCR of 4.22–1.41, an NPV of $252–$1,989, and a payback period of 43–14 months (over 60,000 to 180,000 VMT/year). The BCAs also showed equally impressive results for varying discount rates, initial costs for RSC, financing, extended service life, small carriers, and high-value cargo. Murray et al.,[9] estimated the carrier BCR in RSC deployment to be 1.66–9.36 with a 3 percent discount (depending on VMT). The carrier BCR in the current study was much higher than reported in Murray et al.[9] The difference in the RSC-related crash rate between the non-RSC and RSC cohorts in the current study was almost twice as effective as reported in Murray (0.024 versus a high of 0.015, respectively).

The lack of statistically significant findings for FCW was most likely due to statistical power issues at the expected effectiveness levels. It was projected that there was potentially borderline-sufficient statistical power to be able to detect FCW effectiveness in higher than expected range from previous studies but the results were statistically non-significant. There simply was not enough number of FCW-equipped vehicles in the dataset to be able to statistically detect safety benefits at the projected effectiveness levels.

While insufficiency of the FCW-relevant data in the dataset can explain the "statistical non-significance" of the observed safety benefits with FCW systems, the confounding effects of the driver being in the loop potentially affected the observed effectiveness levels. Battelle[35] and Fitch et al.,[10] used naturalistic truck data to model the benefits of FCW systems (both found that FCW could reduce approximately 21 percent of FCW-related crashes). Fitch et al.,[10] assumed a perfect truck driver response to the FCW alert when modeling the effectiveness of FCW. The data in the current study suggest this may not be the case in the real world. A recent naturalistic truck driving study by Sayer et al.,[11] may explain the lack of significant findings for FCW. Sayer et al.,[11] found that FCW had a marginal effect on headway (improved by only 0.05s) and no significant effect on forward conflict level when approaching preceding vehicles. It appears that most of the reduction in FCW-related crashes was due to CMBS (20.7 percent reduction in FCW-related crash rate). However, this was not significant due to low power (only 20 crashes). Unlike FCW modeling, CBMS does not need to account for driver perception and reaction time, and responds for the driver. The result (though non-significant) supports the estimated reduction in FCW-related crashes reported by Fitch et al.[10] Although the CMBS analysis was inconclusive, it looks like this is a promising technology; however, the current study was not designed to assess the efficacy of CMBS (did not actively recruit carriers with CMBS) and did not have adequate power (only 20 FCW-related crashes from 3,917 truck-years with CMBS). Also note the driver and safety manager FCW focus groups were very positive.

Due to the lack of a statistically significant safety benefit associated with FCW in FCW-related crashes, benefit-cost analyses are not meaningful, and therefore, not included in this report.

4.2.2 Driver and Safety Manager Opinions and Perceptions of OBSSs

Overall, drivers and carrier staff liked having the OBSSs on their trucks; they believed the systems were beneficial and increased safety. Drivers and staff believed the systems aided in keeping drivers alert and teaching them safe driving habits, such as maintaining a safe following distance, using their turn signals when making a lane change, and reducing their speed as they approached curves and turns. Both drivers and carrier staff recognized the relationship between safety, job retention, and company reputation; they appreciated how the OBSSs reflected their company's safety culture.

Drivers and staff recognized the OBSS training received by drivers needed improvement (e.g., an illustration of poor training included drivers being unaware the CMBS engaged the truck's brake lights upon activation). Drivers were curious about the equipment installed on their trucks and wanted more technical information on how the OBSSs functioned and hands-on training and experience prior to making revenue-producing deliveries with the OBSS. Drivers disliked the loss of authority associated with the OBSSs and requested more authority, such as reducing the sensitivity of the OBSS; however, staff indicated this type of control would be problematic in practice as drivers may abuse and manipulate the OBSS (e.g., by turning off the OBSS).

Carrier staff expressed concern that drivers may become overly reliant on the OBSS and lose focus on the driving task. Carrier staff also noted the significant costs associated with purchasing the OBSSs, installing the systems, repairing the systems, and the time and resources spent on training drivers to use the systems. In relation to these costs was the belief by staff that these technologies become obsolete very quickly, thereby requiring software upgrades and purchase of newer models. Although carrier staff expressed frustration in investing money and resources into systems that may become obsolete within a few years, they also recognized the safety benefits and long-term savings associated with each OBSS.

4.2.2.1 Recommendations

Based on the focus groups, there were several recommendations. Drivers and carrier staff agreed that OBSS training needed improvement and suggested giving drivers an opportunity to experience these systems, in a simulator or controlled practice environment, prior to making a revenue-producing delivery. Carrier staff suggested using driver testimonials in support of the OBSS to facilitate driver acceptance of these systems. As drivers were curious about the technical functioning of these systems, training should be expanded to the functional capabilities and limitations of these systems.

Several recommendations concern the OBSS manufacturers. As carrier staff expressed concerns regarding the obsolescence of each OBSS, OBSS manufacturers should consider building scalable hardware devices that require software upgrades rather than new hardware purchases. Carrier staff requested easier access to the data collected by the OBSS to be able monitor their drivers. Enabling wireless downloads from the OBSS, rather than manual downloads, will allow more convenient access to data. Easier access to the data would enable staff to monitor drivers more closely, provide feedback on their driving behavior, and implement targeted training to drivers, if needed. Lastly, drivers recommended the OBSSs include features that allow them to control the sensitivity of the OBSSs in certain situations and scenarios. For example, drivers could override the CMBS system in wet or icy conditions. However, carrier staff expressed concern that drivers may abuse these privileges and override the systems to the degree that these systems become ineffective (as they are always off).

4.3 LIMITATIONS

Although the dataset used in the analyses to assess the efficacy and cost-benefit of each OBSS was comprehensive, there were several limitations.

- The crash files obtained from participating carriers could have contained errors. In turn, these errors could have influenced the efficacy of each OBSSs and the BCAs. There was no way to determine the veracity of the crash files.
- It was possible, albeit unlikely, that safety personnel at participating carriers with an OBSS may have been biased when populating the information in the crash file (e.g., assigning a different crash type and narrative to support the expense in purchasing the OBSS).
- The dataset in the current study was skewed toward larger, for-hire carriers and may not represent the overall U.S. trucking population.
- Estimates of crash costs were used in the current study given the difficulty in obtaining actual crash costs (e.g., unwillingness of carriers to provide this information, time involved in litigation, etc.). It is possible these estimates misrepresent the actual crash costs and favorably/unfavorably skew the BCAs.
- Data analysts (although blind to the specific hypotheses) were not blind to cohort assignment, as they required this information to code OBSS-related crashes; thus, it is possible there was bias on the part of the data analysts (though the inter-rater reliability suggests otherwise).
- The research team had no information on the functionality of each OBSS installed on a truck (i.e., the research team could not verify if the OBSS was malfunctioning).
- The LDW, RSC, and FCW systems in the current study were mostly older-generation systems; thus, the results may not reflect the effectiveness of newer-generation systems.
- No driver information was collected; thus, it is possible that a few drivers were overrepresented in the crashes and the difference in the OBSS-related crash rate may have been the result of these drivers and not the OBSSs.
- The installation of each OBSS was assumed to be random in the current study. No information was collected on the approach used by carriers to install the OBSSs. It is possible that carriers used a deliberate approach in selecting which trucks to install with an OBSS (e.g., only on new trucks).
- 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, there were a considerable number of carriers that had trucks with and without a specific OBSS (thereby alleviating this issue).
- Observed efficacies of these OBSSs may have results attributable to their implementation by the respective manufacturers.

4.4 FUTURE RESEARCH

Although the current study involved the collection of comprehensive truck, carrier, and crash 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 each OBSS. The current study design could be expanded to include a larger, more representative sample. Although there were 151,624 truck-years and 88,112 crashes in the dataset, the number of OBSS-related crashes represented a small proportion of these (4.8 percent of the total crashes). The results in the current study indicate that CMBS may be a promising technology. The current study was not designed to assess CMBS due to its limited deployment in the fleets that participated. Similarly, the study could not assess the effect of electronic stability control due to its limited deployment in the fleets that participated. Electronic stability control provides assistance during loss of control events in addition to roll stability control events, and further, due to its use of additional sensors, it could have higher overall rollover mitigation effectiveness than RSC systems alone.

APPENDIX A: DOCUMENT SUMMARY TABLES

Table 61. FCW System Documents.

Reference	Relevant Issues Covered	Status
Sensors, safety systems, and human factors. (1996). (Report No. SP-1190). Warrendale, PA: Society of Automotive Engineers.	None.	Not Reviewed.
Abe, G., and Richardson, J. (2006). Alarm timing, trust and driver expectation for forward collision warning systems. *Applied Ergonomics, 37*(5), 577-586.	None.	Not Reviewed.
Abe, G., and Richardson, J. (2006). The influence of alarm timing on driver response to collision warning systems following system failure. *Behaviour & Information Technology, 25*(5), 443-452.	None.	Not Reviewed.
Battelle. (2007). *Evaluation of the Volvo intelligent vehicle initiative field operational test. Version 1.3*. Washington, DC: Department of Transportation. http://ntl.bts.gov/lib/jpodocs/repts_te/14352_files/14352.pdf	Heavy Trucks, MOEs, OBSS, other Information.	Reviewed.
Battelle. (2004). *Phase II driver survey report: Volvo intelligent vehicle initiative field operational test.* Washington, DC: Department of Transportation. http://ntl.bts.gov/lib/jpodocs/repts_te/14122_files/14122.pdf	Heavy trucks, MOEs, OBSS.	Reviewed.
Cuelho, E. (2000). An evaluation of intelligent vehicle technologies on rural snowplows. *Proceedings of the ITS 10th Annual America Meeting* [CD ROM].	MOEs, OBSS.	Reviewed.
Curry, R.C., Greenberg, J.A., and Kiefer, R.J. (2005). *Forward collision warning requirements project. Task 4 final report.* (Report No. DOT HS 809 925). Washington, DC: National Highway Traffic Safety Administration.	MOEs, OBSS.	Reviewed.
Curry, R., Blommer, M., Greenberg, J.A., and Tijerina, L. (2009). Immediate recall of driver warnings in forward collision warning scenarios. *Proceedings of the Transportation Research Board 88th Annual Meeting* [CD ROM].	MOEs.	Reviewed.
Eberhard, C.D., Moffa, P.J., and Swihart, W.R. (1996). Forward collision warning systems opportunities study using Monte Carlo simulations. *Proceedings of Intelligent Transportation: Realizing the Future. Third Annual World Congress on Intelligent Transport Systems,* 00491.pdf.	None.	Not Reviewed.
Eberhard, C.D., Moffa, P.J., and Swihart, W.R. (1998). Collision warning. *Automotive Engineering, March,* 115-119.	None.	Not Reviewed.
Eberhard, C.D., Moffa, P.J., and Swihart, W.R. (1996). Taxonomy and size assessments for forward impact crashes applicable to forward collision warning systems. *Sensors, Safety Systems, and Human Factors,* 1-11. (See item 1)	None.	Not Reviewed.
Ervin, R., Sayer, J., Leblanc, D., Bogard, S., Mefford, M., Hagan, M., et al. (2005). *Automotive collision avoidance system field operational test report: Methodology and results.* (Report No. DOT HS 809 900). Washington, DC: National Highway Traffic Safety Administration. http://hdl.handle.net/2027.42/49539	MOEs, OBSS.	Reviewed.
Fancher, P., Bareket, Z., and Ervin, R. (2001). Human-centered design of an acc-with-braking and forward-crash warning system. *Vehicle System Dynamics, 36*(2-3), 1-22.	MOEs.	Reviewed.

Reference	Relevant Issues Covered	Status
Farber, E., and Huang, M. (1995). Rear-end collision-warning algorithms with headway warning and lead vehicle deceleration information. *Proceedings of Steps Forward. Intelligent Transport Systems World Congress, 3*, 1128-1133.	None.	Not Reviewed.
Federal Motor Carrier Safety Administration. (2009). *Benefit-cost analyses of onboard safety systems [Tech Brief].* (Report No. FMCSA-RRT-09-023). Author.	Contains same data as another report.	Not Reviewed.
General Motors. (2005). *Automotive collision avoidance system field operational test final program report.* (Report No. DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration. http://ntl.bts.gov/lib/jpodocs/repts_te/14244.htm	MOEs, OBSS.	Reviewed.
General Motors & Delphi Delco Electronics Systems. (2002). *Automotive collision avoidance field operation test. Warning cue implementation summary report.* (Report No. DOT HS 809 462). Washington, DC: National Highway Traffic Safety Administration.	MOEs, OBSS.	Reviewed.
Gish, K.W., Mercadante, M., Perel, M., and Barickman, F. (2002). The effect of false forward collision warnings on driver responses. *Proceedings of the Transportation Research Board 81st Annual Meeting* [CD ROM].	MOEs.	Reviewed.
Groeger, J.A. (1998). Close, but no cigar: Assessment of a headway warning device. *IEEE Colloquium on Automotive Radar and Navigation Techniques,* 5-1 - 5/4.	MOEs.	Reviewed.
Jamson, A. H., Lai, F.C.H., and Carsten, O.M.J. (2008). Potential benefits of an adaptive forward collision warning system. *Transportation Research Part C: Emerging Technologies, 16*(4), 471-484.	MOEs.	Reviewed.
Kiefer, R.J., Cassar, M. T., Flannagan, C. A., Jerome, C. J., and Palmer, M. D. (2005). *Surprise braking trials, time-to-collision judgments, and "first look" maneuvers under realistic rear-end crash scenarios.* (Report No. DOT HS 809 902). Washington, DC: National Highway Traffic Safety Administration.	MOEs, OBSS.	Reviewed.
Kiefer, R J., Cassar, M.T., Flannagan, C.A., Leblanc, D.J., Palmer, M.D., Deering, R.K., et al. (2003). Forward collision warning requirements project: Refining the CAMP crash alert timing approach by examining "last-second" braking and lane change maneuvers under various kinematic conditions. (Report No. DOT HS 809 574). Washington, DC: National Highway Traffic Safety Administration.	MOEs.	Reviewed.
Kiefer, R., Leblanc, D., Palmer, M., Salinger, J., Deering, R., and Shulman, M. (1999). *Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems.* (Report No. DOT HS 808 964). Washington, DC: National Highway Traffic Safety Administration.	None.	Reviewed.
Kimura, K., Nakagoshi, A., and Kanamori, H. (2007). Estimation of driver inattention to forward objects using facial direction with application to forward collision avoidance systems. *Proceedings of the Driving Assessment 2007: 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, 473-480.	None.	Not Reviewed.
Koopmann, J., and Najm, W.G. (2004). Characterizing the capability of a rear-end crash avoidance system. In D. Holt (Ed.) *Recent Developments in Automotive Safety Technology* (pp. 669-676). Warrendale, PA: Society of Automotive Engineers.	None.	Not Reviewed.

Reference	Relevant Issues Covered	Status
Leblanc, D.J., Bareket, Z., Ervin, R D., and Fancher, P. (2002). Scenario-based analysis of forward crash warning system performance in naturalistic driving. *Proceedings of the 9th World Congress on Intelligent Transport Systems.*	MOEs, OBSS.	Reviewed.
McGehee, D.V., Brown, T.L., Lee, J.D., and Wilson, T.B. (2002). Effect of warning timing on collision avoidance behavior in a stationary lead vehicle scenario. *Transportation Research Record, 1803*, 1-7.	MOEs	Reviewed.
McLaughlin, S.B., Hankey, J.M., and Dingus, T.A. (2008). A method for evaluating collision avoidance systems using naturalistic driving data. *Accident Analysis & Prevention, 40*(1), 8-16.	None.	Not Reviewed.
Misener, J.A., Sengupta, R., and Krishnan, H. (2005). Cooperative collision warning: Enabling crash avoidance with wireless technology. *Proceedings of the 12th World Congress on Intelligent Transport Systems*.	None.	Not Reviewed.
Murray, D., Shackelford, S., and Houser, A. (2009). *Analysis of benefits and costs of forward collision warning systems for the trucking industry.* (Report No. FMCSA-RRT-09-021). Washington, DC: Federal Motor Carrier Safety Administration. http://www.fmcsa.dot.gov/facts-research/research-technology/report/09-021-RP-Forward-Collision.pdf	Heavy trucks, MOEs, OBSS.	Reviewed.
Najm, W.G., Stearns, M.D., Howarth, H., Koopmann, J., and Hitz, J. (2006). *Evaluation of an automotive rear-end collision avoidance system.* (Report No. DOT-VNTSC-NHTSA-06-01. HS-810 569). Research and Innovative Technology Administration. Volpe National Transportation Systems Center. National Highway Traffic Safety Administration.	MOEs, OBSS.	Reviewed.
Ravani, B., Yen, K.S., Tan, H.-S., Steinfeld, A., Thorne, C.H., Bougler, B., et al. (1999). *Advanced snowplow development and demonstration: Phase I: Driver assistance.* (Report No. UCD-ARR-99-06-30-33). Davis: University of California, Advanced Highway Maintenance and Construction Technology Center.	MOEs, OBSS.	Reviewed.
Zhang, W.-B., Shladover, S.E., and Zhang, Y. (2007). Evaluation of forward collision warning system for urban driving. *Transportation Research Record, 2000*, 106-113.	MOEs, other information.	Reviewed.

Table 62. LDW System Documents.

Reference	Relevant Issues Covered	Status
Integrated Vehicle-Based Safety Systems First Annual Report. (2007). (Report No. FHWA-JPO-08-024). Ann Arbor: University of Michigan Transportation Research Institute.	Other information.	Not Reviewed.
Road departure crash warning field operational test. (2004). *UMTRI Research Review, 35*(2), 1-6.	Contains same data as another report.	Not Reviewed.
Ayres, G., Wilson, B., and Leblanc, J. (2004). Method for identifying vehicle movements for analysis of field operational test data. *Transportation Research Record, 1886*, 92-100.	Other information.	Not Reviewed.
Battelle. (2003). *White paper: Mn/DOT Driver acceptance: IVI FOT evaluation report.* (Report No. FHWA-OP-03-182). Washington, DC: Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE//13868.html	MOEs.	Reviewed.
Cummings, M.L., Kilgore, R.M., Wang, E. Tijerina, L., and Kochhar, D.S. (2007). Effects of single versus multiple warnings on driver performance. *Human Factors, 49*(6), 1097-1106.	Contains same data as another report.	Not Reviewed.
Emery, L. (2003). *Interim report on road departure crash warning subsystems.* (Report No. DTFH61-01-X-00053). Ann Arbor: University of Michigan Transportation Research Institute.	MOEs, other information.	Not Reviewed.
Emery, L., Srinivasan, G., Bezzina, D.A., Leblanc, D., Sayer, J.R., Bogard, S E., and Pomerleau, D. (2005). Status report on USDOT project "An intelligent vehicle initiative road departure crash warning field operational test" (05-0198-O.Pdf). *Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles.*	None.	Not Reviewed.
Ervin, R.D., Johnson, G., Venhovens, P., Macadam, C.C., Ulsoy, A.G., Leblanc, D.J., et al. (1995). *The Crewman's Associate for Path Control (CAPC): An automated driving function.* (Report No. UMTRI-95-35). Ann Arbor: University of Michigan Transportation Research Institute.	Other information.	Not Reviewed.
Federal Motor Carrier Safety Administration. (2009). *Benefit-cost analyses of onboard safety systems [Tech Brief].* (Report No. FMCSA-RRT-09-023). Author.	Contains same data as another report.	Not Reviewed.
Griffin, M.J., Johnson, S.L., Nam, C.S., and Racheru, K. (2007). Development of a human performance simulation model to evaluate in-vehicle information and control systems in commercial trucking operations. Fayetteville, AR: Mack-Blackwell Rural Transportation Center.	Heavy trucks, other information.	Not Reviewed.
Hadi, M. a., Sinha, P. K., & Easterling IV, J. R. (2007). Effect of environmental conditions on performance of image recognition-based lane departure warning system. *Transportation Research Record, 2000* , 114-120.	OBSS, other information.	Reviewed.
Ho, A., Cummings, M.L., Kochhar, D.S., Tijerina, L., and Wang, E. (2006). Integrating intelligent driver warning systems: Effects of multiple alarms and distraction on driver performance. *Proceedings of the Transportation Research Board 85th Annual Meeting*.	MOEs	Reviewed.

Reference	Relevant Issues Covered	Status
Hohman, D., Murdock, T., Westerfield, E., and Hattox, T. (2000). GPS roadside integrated precision positioning system. *Proceedings of the IEEE 2000 Position Location and Navigation Symposium*, 221-230.	OBSS, other information.	Not Reviewed.
Houser, A., Murray, D., Shackelford, S., Kreeb, R., and Dunn, T. (2009). *Analysis of benefits and costs of lane departure warning systems for the trucking industry* (FMCSA-RRT-09-022). Washington, DC: Federal Motor Carrier Safety Administration.	Heavy trucks, MOEs, OBSS.	Reviewed.
Huh, K. (1992). *A lane-departure warning and control system.* (Report No. IVHS-TR-92-21). Ann Arbor: University of Michigan Transportation Research Institute.	Other information.	Not Reviewed.
Isomoto, K., Niibe, T., Suetomi, T., and Butsuen, T. (1995). Development of a lane-keeping system for lane departure avoidance. *Proceeding of Steps Forward. Second World Congress on Intelligent Transport Systems, 3*, 1266-1271.	Other information.	Not Reviewed.
Johnson, S.L. (2008). *Human factors study of driver assistance systems to reduce lane departures and side collision accidents* (Project MBTC 2083). Fayetteville, AR: Mack-Blackwell Rural Transportation Center.	Heavy trucks, other information.	Not Reviewed.
Kelly, M. J. , Lassacher, S., and Stanley, L.M. (2007). Formative evaluation of engineering designs using driver performance in an immersive driving simulator. *Proceeding of the Driving Assessment 2007: 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design* (pp. 431-437). Iowa City: University of Iowa.	Other information.	Not Reviewed.
LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, S., et al. (2006). *Road departure crash warning field operational test. Volume 1: Technical report.* (Report No. UMTRI-2006-9-1). Ann Arbor: University of Michigan Transportation Research Institute.	MOEs, OBSS.	Reviewed.
LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, S., et al. (2006). *Road departure crash warning field operational test. Volume 2: Appendices.* (Report No. UMTRI-2006-9-2). Ann Arbor: University of Michigan Transportation Research Institute.	Other information.	Not Reviewed.
Leblanc, D.J. (1996). A warning and intervention system to prevent road-departure accidents. *Proceedings of the 14th IAVSD Symposium: The Dynamics of Vehicles on Roads and on Tracks* 383-396.	OBSS, other information.	Not Reviewed.
Leblanc, D., Sardar, H., Nowak, M., Tang, Z., and Pomerleau, D. (2008). *Functional requirements for Integrated Vehicle-Based Safety System (IVBSS) - Heavy truck platform.* (Report No. UMTRI-2008-17. DTNH22-05-H-01232). Ann Arbor: University of Michigan Transportation Research Institute.	Heavy trucks, other information.	Not Reviewed.
Pilutti, T., and Ulsoy, A.G. (2003). Fuzzy-logic-based virtual rumble strip for road departure warning systems. *IEEE Transactions on Intelligent Transportation Systems, 4*(1), 1-12.	OBSS, other information.	Not Reviewed.
Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J., et al. (2000). *Run-off-road collision avoidance using IVHS countermeasures.* (Report No. DOT HS 809 170). Washington, DC: National Highway Traffic Safety Administration.	Heavy trucks, other information.	Not Reviewed.
Ravani, B., Yen, K.S., Tan, H.-S., Steinfeld, A., Thorne, C.H., Bougler, B., et al. (1999). *Advanced snowplow development and demonstration : Phase I: Driver assistance.* (Report No. AHMCTC Research Report UCD-ARR-99-06-30-33). Davis: University of California, Advanced Highway Maintenance and Construction Technology Center.	Other information.	Not Reviewed.

Reference	Relevant Issues Covered	Status
Rimini-Doering, M., Altmueller, T., Ladstaetter, U., and Rossmeier, M. (2005). Effects of lane departure warning on drowsy drivers' performance and state in a simulator. *Proceedings of Driving Assessment 2005: 3rd International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design,* 88-95.	MOEs	Reviewed.
Suzuki, K., Wakasugi, T., and Soma, H. (2002). Designing method of warning timing based on the time criterion for lane departure warning system. *Transactions of the Society of Instrument and Control Engineers, 38*(6), 567-573.	None.	Not Reviewed.
Szabo, S., Murphy, K., and Juberts, M. (1999). *AUTONAV/DOT project: Baseline measurement system for evaluation of roadway departure warning systems.* (Report No. NISTIR-6300). Gaithersburg, MD: National Department of Commerce.	Other information.	Not Reviewed.
Wilson, B H., and Burgett, A. (2002). Crash prevention boundaries for road departure. *Proceedings of the 9th World Congress on Intelligent Transport Systems*.	Other information.	Not Reviewed.
Wilson, B,H. (2008). Safety benefits of a road departure crash warning system. *Proceedings of the Transportation Research Board 87th Annual Meeting*.	Other information.	Not Reviewed.
Wilson, B,H, Stearns, M.D., Koopmann, J., and Yang, C.Y.D. (2007). *Evaluation of a road-departure crash warning system.* (Report No. DOT HS 810 854). Washington, DC: National Highway Traffic Safety Administration.	MOEs, OBSS.	Reviewed.
York, J., and Maze, T.H. (1997). Economic evaluation of truck collision warning systems. *Transportation Research Circular*, (475), 46-50.	Heavy trucks.	Not Reviewed.

Table 63. Electronic Stability Control Documents.

Reference	Relevant Issues Covered	Status
American Transportation Research Institute. (2009). *A synthesis of commercial motor vehicle safety technology surveys: What have we learned?* Arlington, VA: Author. http://www.atri-online.org/index.php?option=com_content&view=article&id=58&Itemid=69	Heavy trucks, MOEs, other information.	Not Reviewed.
Bahouth, G. (2005). Real world crash evaluation of Vehicle Stability Control (VSC) technology, *Association for the Advancement of Automotive Medicine 49th Annual Conference*, 19-34.	MOEs, OBSS.	Reviewed.
Bartlett, W., and Wright, W.J. (2008). Summary of 56 recent critical speed yaw analysis tests including ABS and electronic stability control on pavement, gravel, and grass. *Accident Reconstruction Journal, 18*, 29-32.	Other information.	Not Reviewed.
Battelle. (2003). *Final report – Evaluation of the Freightliner intelligent vehicle initiative field operational test* (Contract No. DTFJ61-96-C-00077, Task Order 7718). Washington, DC: Federal Highway Administration. http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE//13871.html	Heavy trucks, MOEs, OBSS.	Reviewed.
Blower, D.F., Woodrooffe, J., Green, P., Matteson, A., and Shrank, M. (2005). Determination of events leading to sport utility vehicle rollover. *Transportation Research Record,* 180-186.	None.	Not Reviewed
Blue, D.W., and Kulakowski, B.T. (1991). Effects of horizontal-curve transition design on truck roll stability. *Journal of Transportation Engineering, 117*, 91-102.	None.	Not Reviewed.
Bogard, S.E., Winkler, C.B., and Campbell, K.L. (1992). *Sensitivity analysis of the tilt table test methodology. Final technical report* (UMTRI-92-12). Ann Arbor: University of Michigan Transportation Research Institute. http://deepblue.lib.umich.edu/handle/2027.42/961?mode=full	Heavy trucks, other information.	Not Reviewed.
Choi, S.B. (2008). Practical vehicle rollover avoidance control using energy method. *Vehicle System Dynamics, 46*(4), 323-337.	Other information.	Not Reviewed.
Commander, U.S. Army Combat Systems Test Activity. (1993). *Test Operations Procedure (TOP) 2-2-8: Wheeled vehicle center of gravity* (AD-A273 937). Aberdeen Proving Ground, MD: U.S. Army Test and Evaluation Command.	Heavy trucks, other information.	Not Reviewed.
Dang, J.N. (2004). *Preliminary results analyzing the effectiveness of Electronic Stability Control (ESC) systems* (DOT HS 809 790). Washington, DC: National Highway Traffic Safety Administration. http://www.nhtsa.dot.gov/cars/rules/regrev/evaluate/809790_files/809790.pdf	Contains same Data as another report.	Not Reviewed.
Dang, J N. (2007). *Statistical analysis of the effectiveness of Electronic Stability Control (ESC) Systems - Final Report* (DOT HS 810 794). Washington, DC: National Highway Traffic Safety Administration. http://www-nrd.nhtsa.dot.gov/Pubs/810794.PDF	MOEs, OBSS, other information.	Not Reviewed.
Driver behavior, older drivers, simulation, user information systems, and visualization. (2006). *Transportation Research Record* (pp. 150): Transportation Research Board.	None.	Not Reviewed.
Erke, A. (2008). Effects of electronic stability control (ESC) on accidents: A review of empirical evidence. *Accident Analysis & Prevention*, *40*, 167-173.	MOEs, OBSS, other information.	Not Reviewed.
Ervin, R.D. (1983). The influence of size and weight variables on the roll stability of heavy duty trucks. *SAE Technical Paper Series* Warrendale, PA: Society of Automotive Engineers.	Heavy trucks, other information.	Not Reviewed.

Reference	Relevant Issues Covered	Status
Ervin, R.D. (1986). The dependence of truck roll stability on size and weight variables. *International Journal of Vehicle Design, 7,* 192-208.	Heavy trucks, other information.	Not Reviewed.
Ervin, R.D. (1998). *Two active systems for enhancing dynamic stability in heavy truck operations* (Report No. UMTRI-98-39). Ann Arbor: University of Michigan Transportation Research Institute. http://deepblue.lib.umich.edu/handle/2027.42/1257	Heavy trucks, other information.	Reviewed.
Ervin, R.D., and Mathew, A. (1987). *Stability of tank truck combinations on curved road segments in the Yukon. Final report* (Report No. UMTRI-87-9): University of Michigan Transportation Research Institute. http://deepblue.lib.umich.edu/handle/2027.42/77	Heavy trucks, MOEs, OBSS.	Not Reviewed.
Farmer, C.M. (2004). Effect of electronic stability control on automobile crash risk. *Traffic Injury Prevention (5),* 317-325.	MOEs, OBSS.	Reviewed.
Farmer, C.M. (2006). Effects of electronic stability control: An update. *Traffic Injury Prevention, 7*, 319-324.	MOEs, OBSS.	Reviewed.
Federal Motor Carrier Safety Administration. (2009). *Benefit-cost analyses of onboard safety systems [Tech Brief].* (Report No. FMCSA-RRT-09-023). Author.	Contains same Data as another report.	Not Reviewed.
Ferguson, S.A. (2007). The effectiveness of electronic stability control in reducing real-world crashes: A literature review. *Traffic Injury Prevention, 8*, 329-338.	Other information.	Not Reviewed.
Forkenbrock, G.J., and Garrott, W.R. (2004). *Testing the rollover resistance of two 15-passenger vans with multiple load configuration*s (DOT HS 809 704). Washington, DC: National Highway Traffic Safety Administration. http://ntl.bts.gov/lib/30000/30100/30175/809704.pdf	MOEs, OBSS, other information.	Not Reviewed.
Forkenbrock, G.J., Elsasser, D., and Harra, B. (2005). NHTSA's light vehicle handling and ESC effectiveness research program. *Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles* (Paper Number 05-0221). http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0221-O.pdf	MOEs, OBSS, other information.	Not Reviewed.
Freightliner. (2007). *Electronically Controlled Braking Systems (ECBS) intelligent vehicle initiative field operational test. Combined templates 2 and 3: Mixed and optimized tractor-trailer*. Washington, DC: Federal Highway Administration. http://ntl.bts.gov/lib/jpodocs/repts_te/14359_files/ecbs_fot_final_report_20071017.pdf	Heavy trucks, MOEs, OBSS.	Reviewed.
Green, P.E., and Woodrooffe, J. (2006). *The effectiveness of electronic stability control on motor vehicle crash prevention* (UMTRI-2006-12). Ann Arbor: University of Michigan Transportation Research. http://www.umtri.umich.edu/content/ESC_final_draft.pdf	MOEs, OBSS.	Reviewed.
Griffin, M.J., Racheru, K., Johnson, S.L., and Nam, C.S. (2007). *Development of a human performance simulation model to evaluate in-vehicle information and control systems in commercial trucking operations*. Fayetteville, AR: Mack-Blackwell Rural Transportation Center. http://ntl.bts.gov/lib/26000/26900/26967/MBTC-2062.pdf	Other information	Not Reviewed.
Goldman, R., El-Gindy, M., and Kulakowski, B.T. (2005). Development of a software-based rollover warning device. *International Journal of Heavy Vehicle Systems, 12*(4), 282-306.	Heavy trucks, other information.	Not Reviewed.

Reference	Relevant Issues Covered	Status
Hayama, R., Katsutoshi, N., Nakano, S., and Katou, K. (2000). The vehicle stability control responsibility improvement using steer- by-wire. *Proceedings of the IEEE Intelligent Vehicles Symposium 2000*, 596-601.	None.	Not Reviewed.
Heavy vehicle dynamics and stability. (1993). Warrendale, PA: Society of Automotive Engineers.	None.	Not Reviewed.
Houser, A., Murray, D., and Dick, V. (2007). *Onboard safety technology survey synthesis final report*. Washington DC: Federal Motor Carrier Safety Administration.	Heavy trucks, MOEs, OBSS.	Reviewed.
Houser, A., Pape, D., and McMillan (2006). *A simulation approach to estimate the efficacy of Meritor WABCO's improved roll stability control*. Washington DC: Federal Motor Carrier Safety Administration.	Heavy trucks, MOEs, OBSS.	Reviewed.
Kemp, R.N., Chinn, B.P., and Brock, G. (1978).). *Articulated vehicle roll stability: Methods of assessment and effects of vehicle characteristics* (TRLL Laboratory Report 788): Crowthorne, Berkshire: Transport and Road Research Laboratory.	Heavy trucks, MOEs, other information.	Not Reviewed.
Klein, T.M. (2004). A statistical analysis of vehicle rollover propensity and vehicle stability. In Viano, D.C., & Parenteau, C.S. (Eds.), *Occupant and Vehicle Responses in Rollovers* (pp. 341-356). Warrendale, PA: Society of Automotive Engineers.	Other information.	Not Reviewed.
Kreiss, J.-P., Schuler, L., and Langwieder, K. (2005). The effectiveness of primary safety features in passenger cars in Germany, *19th International Technical Conference on the Enhanced Safety of Vehicles* (Paper Number 05-0145). Washington, DC: National Highway Traffic Safety Administration. http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0145-O.pdf	MOEs, OBSS, other information	Not Reviewed.
Li, L., Song, J., Want, H., and Xue, C. (2007). Linear subsystem model for real-time control of vehicle stability control system. *Proceedings of the 2006 IEEE Conference on Robotics, Automation and Mechatronics*.	None	Not Reviewed.
Lie, A., Tingvall, C., Krafft, M., and Kullgren, A. (2006). The effectiveness of Electronic Stability Control (ESC) in reducing real life crashes and injuries, *Traffic Injury Prevention, 7,* 38-43.	None	Not Reviewed.
Linder, A., Dukic, T., Hjort, M., Matstoms, Y, Mårdh, S., Sundström, J., et al. (2007). *Methods for the evaluation of traffic safety effects of Antilock Braking System (ABS) and Electronic Stability Control (ESC): A literature review*. Linköping: Swedish National Road and Transport Research Institute (VTI). http://www.vti.se/EPiBrowser/Publikationer%20-%20English/R580A.pdf	OBSS	Not Reviewed.
Murray, D., Shackelford, S., and Houser, A. (2009). *Analysis of benefits and costs of roll stability control systems for the trucking industry* (FMCSA-RRT-09-020). Washington, DC: Federal Motor Carrier Safety Administration. http://www.fmcsa.dot.gov/facts-research/research-technology/report/09-020-rp-roll-stability.pdf	Heavy trucks, MOEs, OBSS	Reviewed.
NHTSA Study of Rollover Crash Safety. (2004). In Viano, D.C., and Parenteau, C.S. (Eds.), *Occupant and Vehicle Responses in Rollovers* (pp. 219-266). Warrendale, PA: Society of Automotive Engineers.	Other information	Not Reviewed.
Page, Y., and Cuny, S. (2006). Is electronic stability program effective on French roads? *Accident Analysis & Prevention, 38*, 357-364.	None	Not Reviewed.
Pan, W., and Papelis, Y.E. (2005). Real-time dynamic simulation of vehicles with electronic stability control: Modeling and validation. *International Journal of Vehicle Systems Modeling and Testing, 1*(1/2/3), 143-167.	Other information	Not Reviewed.

Reference	Relevant Issues Covered	Status
Pape, D.B., McMillan, N., Greenberg, A., Mayfield, H., Chitwood, J.C., Winkler, C.B., et al. (2008). Benefits and costs of four approaches to improving rollover stability of cargo tank motor vehicles. *Transportation Research Record*, *2066*, 114-121.	Heavy trucks, other information.	Not Reviewed.
Rakheja, S., Romero, J.A., Lozano, A., Liu, P.J., and Ahmed, A.K.W. (2002). Assessment of open-loop rollover control of articulated vehicles under different maneuvers. *Heavy vehicle systems, International Journal of Vehicle Design, 9*(3)*,* 204-222.	Heavy trucks, other information.	Not Reviewed.
Sankar, S., and Surial, S. (1994). A sensitivity analysis approach for fast estimation of rollover stability of heavy articulated vehicles during steady state turning. *Heavy vehicle systems, International Journal of Vehicle Design, 1*(3), 282-303.	Heavy trucks, other information.	Not Reviewed.
Schweers, T.F., and Wallentowitz, H. (1994). Development of possible procedures for testing and rating of traction and stability control systems. *Proceedings of the International Symposium on Advanced Vehicle Control 1994 Tsukuba- shi, Japan* (pp. 128-134). Tokyo: Society of Automotive Engineers Japan.	Other information.	Not Reviewed.
Segawa, M., Nakano, S., Nishihara, O., and Kumamoto, H. (2001). Vehicle Stability Control Strategy for Steer by Wire System, *JSAE Review, 22*(4), 383-388.	None	Not Reviewed.
Stevens, S.S., Chin, S. M., Hake, K.A., Hwang, H.L., Rollow, J.P., and Truett, L.F. (2001). *Truck roll stability data collection and analysis* (ORNL/TM-2001/116): Oak Ridge, TN: Oak Ridge National Laboratory. http://cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2001_116.pdf	Heavy trucks, MOEs, OBSS	Reviewed.
Svenson, A.L., & Hac, A. (2005). Influence of chassis control systems on vehicle handling and rollover stability. *Proceeding of the 19th International Technical Conference on the Enhanced Safety of Vehicles*. http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0324-O.pdf	OBSS, other information	Not Reviewed.
Takano, S., Suzuki, M., Nagai, M., & Taniguchi, T. (2003). Study of a vehicle dynamics model for improving roll stability, *JSAE Review, 24*, 149-156.	Other information.	Not Reviewed.
The National Highway Traffic Safety Administration's rating system for rollover resistance: An assessment. (2002). (Special Report 245). Washington, DC: Transportation Research Board. http://onlinepubs.trb.org/onlinepubs/sr/sr265.pdf	Other information.	Not Reviewed.
Truett, L.F., Hwang, H.L., Chin, S.M., & Stevens, S.S. (2002). Truck roll stability data collection and analysis, *International Truck and Bus Safety Research and Policy Symposium* (pp. 389-396). Knoxville: University of Tennessee.	Contains same data as another report.	Reviewed.
Watson, G.S., Papelis, Y.E., and Ahmad, O. (2006). Design of simulator scenarios to study effectiveness of electronic stability control systems. *Transportation Research Record, 1980*, 79-86.	Other information.	Not Reviewed.
Winkler, C.B. (1987). *Experimental determination of the rollover threshold of four tractor-semitrailer combination vehicles. Final report* (UMTRI-87-31) Ann Arbor: University of Michigan Transportation Research Institute. http://deepblue.lib.umich.edu/handle/2027.42/49?mode=full	Heavy Trucks, Other information.	Not Reviewed.
Winkler, C.B., Blower, D., & Ervin, R.D. (1999). *Rollover of heavy commercial vehicles* (UMTRI-99-19). Ann Arbor: University of Michigan Transportation Research Institute. http://deepblue.lib.umich.edu/bitstream/2027.42/1290/2/93802.0001.001.pdf	Heavy Trucks, Other information.	Not Reviewed.

Reference	Relevant Issues Covered	Status
Winkler, C., Fancher, P., and Ervin, R. (1999). Intelligent systems for aiding the truck driver in vehicle control. In *IV: Vehicle Navigation Systems and Advanced Controls* (pp. 165-178, SAE Paper No. 1999-01-1301). Warrendale, PA: Society of Automotive Engineers.	Contains same data as another report.	Reviewed.
Winkler, C., Sullivan, J., Bogard, S., Goodsell, R., and Hagan, M. (2002). *Field operational test of the Freightliner/Meritor WABCO roll stability advisor and control at Praxair* (UMTRI-2002-24). Ann Arbor: University of Michigan Transportation Research Institute. http://deepblue.lib.umich.edu/bitstream/2027.42/1502/2/96243.0001.001.pdf	Heavy Trucks, MOEs, OBSS.	Reviewed.

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APPENDIX B: OBSS TECHNOLOGY REVIEWER GUIDE

DOCUMENT:

Definition: This field identifies the document by its reference.

Usage: The full reference in APA format should be included.

SAFETY SYSTEM:

Definition: This field indicates which of the vehicle systems is addressed in the document

Usage:

- ESC (Electronic Stability Control), including RSC (Rollover Stability Control), RSS (Rollover Support System), TRSP (Trailer Roll Stability Program).
- LDW.
- FCW.

Note: Indicate the type of system used or defining in brackets (e.g., RSS, RSC, etc)

VEHICLE TYPE:

Definition: This field indicates what type of vehicle was used in the research

- Usage (list all that apply):
- Heavy Truck
- Passenger Vehicle/Light Truck
- Service Vehicle (e.g., Emergency vehicles, Snow-plows, etc)
- Other (list)

METHOD/STUDY TYPE:

Definition: This field provides a general categorization of the main approach(es) used for collecting/synthesizing the primary data or information.

Usage:

- A categorical field that consists of one or more of the following terms:
  - On-road study
  - Closed track study
  - Driving simulator study

- Field Test
- Laboratory study
- Crash Data Analysis
- User Requirements Analysis
- Literature Review/Synthesis
- Meta Analysis
- Design Guidelines/Standards
- Integrative Research Review
- Feasibility Study
- Commentary

GENERAL APPROACH:

Definition: This field briefly describes how the researchers performed their research. Core methodological details (e.g., number of participants; technology used, etc.) should be included in this field.

Usage:

- One sentence describing the test conditions, such as the apparatus and/or location of the study.
- One sentence describing the general procedure, while not providing excessive detail about the methods.

A common format should be used for describing elements that occur repeatedly (e.g., Forty participants drove an instrumented vehicle on a one-half-km closed-loop test-track…). Studies presenting multiple data collection activities can be described at a more general level (e.g., Four studies were conducted that looked the effects of X_1, X_2, & X_3 on Y)

MEASURES OF EFFECTIVENESS (MOES):

Definition: This Section describes the MOEs used in the report to evaluate the safety or driver-performance aspects related to the technologies examined.

Usage:

- List each MOE and provide a brief description of what it measures, and the rationale for using it (if this is not obvious).

RESEARCH/SOURCE QUALITY:

Definition: This field provides a general evaluation of the overall quality of the methods and results described in the data source. This information is useful for evaluating the validity and reliability MOEs.

Usage:

- One of three quality categories should be indicated. These include:
  - *High*: Represents high or exceptional quality research involving a comprehensive and definitive look at issue (e.g., looked at many parameters, ample data, etc)
  - *Medium*: Represents established and sound methodology and has no obvious or serious flaws; conclusions are supported by data
  - *Low*: Represents lower quality research; conclusions may not be supported by data or the research has significant methodological flaws that put validity of results into question

QUALITY NOTE:

Definition: This field provides comments or justification for the assigned quality level.

Usage:

- This field is primarily for identifying reasons why a quality level was assigned. The specific flaws, etc. should be summarized in a single brief sentence. There is no need to provide a note if the rating is high.

The primary purpose of this field is to avoid having to re-read the source document to remember/figure out why a particular value was assigned.

RESEARCH/SOURCE APPLICABILITY:

Definition: This field provides a general evaluation of the overall applicability of results, conclusions, and recommendations.

Usage:

- One of three quality categories should be indicated. These include:
  - *High*: Represents research that uses or discusses the use of MOEs to evaluate the safety systems in heavy trucks in a relevant driving context.
  - *Medium*: Represents research that may not directly involve safety systems or heavy trucks, but instead has useful information about MOEs or the applicability or validity of MOEs when used to evaluate safety systems. It captures the middle ground between high and low applicability data. *Relevant research conducted in light vehicles would also fall under this category.*

  - *Low*: Represents tangentially related research from which only general principles can be drawn, and even this requires interpretation or extrapolation of results.

APPLICABILITY NOTE:

Definition: This field provides comments or justification for the assigned applicability level.

Usage:

- This field should list the specific reasons the assigned applicability level was provided. There is no need to provide a note if the rating is high.

The primary purpose of this field is to avoid having to re-read the source document to remember/figure out why a particular value was assigned.

KEY FINDINGS AND RECOMMENDATIONS:

Definition: This field summarizes the key findings and representations from the source document.

Usage:

- This information will form the primary bases for evaluating and describing the utility of MOEs, however, brevity is preferred over lengthy discussion and examples.
- Results with demonstrated implications for safety should be highlighted
- Results should be described in as quantitative a manner as possible and they should refer to the relevant Independent Variables (e.g., Stopping distances were 10 meters shorter in condition X).
- Important and relevant opinions or judgments expressed by the data-source authors can also be included. However, these should be prefaced with the word "Opinion." For example: "*Opinion*: A good rule of thumb for X seems to be …"

CAVEATS/COMMENTS:

Definition: This field captures any additional information that is relevant to the source document that was not indicated in other fields.

Usage:

- This Section might be used to expand on the following issues:
  - Expand on the Quality or Applicability Notes if additional important information warrants discussion
  - Indicate if the quality or applicability differs for different sets of results and conclusions in the document
  - Any other noteworthy comments about the results or methods.

APPENDIX C: LITERATURE REVIEWS

FCW REVIEWS

Document: Battelle. (2007). *Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test. V1.3* Washington, DC: Department of Transportation.
Safety System: FCWS (VORAD)
Vehicle Type: Heavy Truck
Study Type: Field Study—Field Operational test
General Approach: 50 vehicles were equipped with a suite of collision avoidance devices for up to 3 years. Drivers were US Xpress employees. Both an experimental and control group were used; baseline measures were obtained.
Measures of Effectiveness: 1) Safety benefits—changes in conflicts and crashes, driver behavior (e.g., following distance). 2) Driver acceptance (see also Battelle, 2004). 3) Benefits-cost analysis; i.e., reduction in crashes, injuries, deaths relative to the cost of purchasing and installing the devices.
Quality: High
Quality Note:
Applicability: High
Applicability Note: The topics addressed in the evaluation reflect a number of important questions about the usefulness and effectiveness of FCW devices.
Key Findings and Recommendations: - The FCWS reduced the risk of a rear-end collision by 21% and helped drivers maintain longer following distances. - Overall, drivers reported no major problems with the system and had a positive reaction to VORAD. The system did not seem to present a distraction, though drivers disliked nuisance alerts. They understood the system and its potential benefits. Drivers believed that the technology helped them drive more safely. - Overall economic benefits were observed, but only if the costs of the technology can be reduced in the future.
Caveats/Comments: See also Battelle, 2004 for a more complete discussion of the driver surveys.

Document: Battelle. (2004). *Phase II Driver Survey Report: Volvo Intelligent Vehicle Initiative Field Operational Test.* Washington, DC: Department of Transportation.
Safety System: FCWS
Vehicle Type: Heavy Truck
Study Type: Field Study—Field Operational Test
General Approach: 50 vehicles were equipped with a suite of collision avoidance devices for up to 3 years. Drivers were US Xpress employees. Both an experimental and control group were used; baseline measures were obtained. Drivers were sent a notification to call an 800 number in order to obtain the survey data. Overall response rates were above 50%.
Measures of Effectiveness: All MOEs reported here were obtained through telephone surveys of the drivers. 1) Driver perceptions of usability—how the systems are used and understood by the drivers. Included an understanding of displays and controls and well as how the information provided by the system could be used. 2) Usefulness of training. 3) Ease of seeing/hearing warnings, distinguishable from one another and from other system warnings. 4) Driver workload—distraction of the system, reactions to nuisance alerts, trust in the system, perceived effectiveness.
Quality: Medium
Quality Note: Only qualitative survey data are reported—no behavioral or performance data.
Applicability: Medium
Applicability Note: The topics addressed in the driver surveys reflect a number of important questions about the usefulness and effectiveness of FCW devices.
Key Findings and Recommendations: - Overall, drivers reported no major problems with the system and had a positive reaction to the Eaton VORAD system. The system did not seem to present a distraction, though drivers disliked nuisance alerts. They understood the system and its potential benefits. Drivers believed that the technology helped them drive more safely
Caveats/Comments: The measures listed above are just a sample of the many topics addressed in the surveys. See also Battelle, 2007 for a more complete evaluation of the Volvo system.

Document: Cuelho, E. (2000). An Evaluation of Intelligent Vehicle Technologies on Rural Snowplows. *Proceedings of the ITS 10th Annual America. Meeting* , 0030.pdf.
Safety System: FCWS & LDS
Vehicle Type: Snowplows
Study Type: Field study
General Approach: The CAS-equipped snowplows were utilized along- side non-equipped snowplows during the winter of 1998-1999 near Donner Pass, CA. Before-after comparisons were made where possible.
Measures of Effectiveness: 1) Safety: accidents, repair/replacement costs (based on reports). 2) Improved operational efficiency & mobility: number of miles cleared per hour, frequency and duration of road closured, frequency of snowplow-related incidents (based on reports). 3) General benefits: frequency & severity of components malfunction, perceived benefits or malfunctions, frequency and severity of human errors associated with the system, operator assessment of system accuracy and reliability, recommendations for improving the system (operator interviews and ride-alongs were conducted).
Quality: Low
Quality Note: Despite their best attempts, the evaluation appeared incomplete. Many of the variables that they had intended to measure either were not measurable, were not measured at all, or were not measured for both the before/after conditions.
Applicability: Medium
Applicability Note: Despite the incomplete data, the intended MOEs reflected a useful mix of quantitative and qualitative measures, with a focus on before/after measurements. The exact measures used will be different for OBSSs in heavy trucks, but the measures used here may have some relevant parallels.
Key Findings and Recommendations: - As noted above, the quantitative measures did not work out as planned due to insufficient amount of comparative data. - Driver reactions to the system obtained during the telephone interviews and ride-alongs were generally positive.
Caveats/Comments: This is the same project as: Ravani, B., Yen, K. S., Tan, H.-S., Steinfeld, A., Thorne, C. H., Bougler, B., et al. (1999). *Advanced snowplow development and demonstration : Phase I: Driver assistance.* (Report No. UCD-ARR-99-06-30-33). Davis: University of California, Advanced Highway Maintenance and Construction Technology Center.

Document: Curry, R. C., Greenberg, J. A., & Kiefer, R. J. (2005). *Forward Collision Warning Requirements Project. Task 4 Final Report.* (Report No. DOT HS 809 925). Washington, DC: National Highway Traffic Safety Administration.
Safety System: FCWS
Vehicle Type: Passenger Vehicle
Study Type: Simulator Study
General Approach: Examined drivers' last-second braking and steering judgments in the National Advanced Driving Simulator (NADS) (4000 test runs) and compared the results to those obtained in a field study.
Measures of Effectiveness: 1) Last-second braking and steering behaviors.
Quality: High
Quality Note:
Applicability: Low
Applicability Note: The focus was on how NADS data could be correlated to real-world data for rear-end driving scenarios.
Key Findings and Recommendations: - Scenarios should have comparable initial headway conditions, should emphasize high deceleration of lead vehicles, should emphasize cases where the relative speed differential is high, and should emphasize last-second braking or hard steering. - Last second maneuver onset behavior, not crash rates, should be used.
Caveats/Comments: - The emphasis here was on examining fine-grained driver performance once an alert has been issued. The assumption seems to be that whatever happens prior to the "last second" may be noisy and harder to compare across research environments. - This was a follow-on to earlier CAMP work (Kiefer, R. J., Cassar, M. T., Flannagan, C. A., Leblanc, D. J., Palmer, M. D., Deering, R. K., & Shulman, M. A. (2003). *Forward Collision Warning Requirements Project: Refining the CAMP Crash Alert Timing Approach by Examining "Last-Second" Braking and Lane Change Maneuvers Under Various Kinematic Conditions.* (Report No. DOR HS 809 574). Washington, DC: National Highway Traffic Safety Administration.)

Document:
Curry, R., Blommer, M., Greenberg, J. A., & Tijerina, L. (2009). Immediate Recall of Driver Warnings in Forward Collision Warning Scenarios. *Proceedings of the Transportation Research Board 88th Annual Meeting*.

Safety System:
FCWS

Vehicle Type:
Passenger Vehicle

Study Type:
Driving Simulator Study

General Approach:
120 subjects participated in a simulator study in which a single FCW alert was given (auditory, visual, or both). Half of the subjects were told that the FCW system was present in the simulated system, and half were not. A digit reading task was also included. Immediately after the last repetition of the digit reading task, the alert was presented, followed by a recall task.

Measures of Effectiveness:
1) Immediate recall of FCW alerts: (a) did you receive a warning and (b) what do you recall about the warning?

Quality:
High

Quality Note:
Though focused on a unique and specific MOE, the study was well-designed and executed.

Applicability:
Low-Medium

Applicability Note:
It is not practical to measure immediate recall in the field; though some measures of recall may be useful.

Key Findings and Recommendations:

- 26% of the subjects did not remember receiving a warning.
- 58% of those who recollected receiving a warning recalled at least 1 of the modalities correctly, though 90% of those who received both the auditory/visual combination warning recalled at least one of the modalities.
- Those who were told that the FCW system was present in the simulated system had significantly better recollection than those who were not.

Caveats/Comments:
None

Document: Ervin, R., Sayer, J., Leblanc, D., Bogard, S., Mefford, M., Hagan, M., Bareket, Z., & Winkler, C. (2005). *Automotive collision avoidance system field operational test report: Methodology and results.* (Report No. DOT HS 809 900). Washington, DC: National Highway Traffic Safety Administration.
Safety System: FCWS
Vehicle Type: Passenger Vehicle
Study Type: Field Study - FOT
General Approach: 11 ACAS-equipped passenger vehicles were drives for 12 months by 96 lay drivers—the FOT included more than 137,000 vehicle miles. Drivers included equal numbers of males and females in their 20s, 40s, and 60s. The first week of driving for all participants was conducted with the system off. Three changes in the alert algorithm were made during the test—the results below reflect 66 subjects' worth of data with the final algorithm.
Measures of Effectiveness: 1) Alert rate and alert scenarios. 2) Driver perception of the utility of the alert, perceived urgency. 3) Driver headway, especially changes in headway over time. 4) Driver behavior during closing-type conflicts. 5) Effects on braking behavior. 6) Effects on secondary task behavior. 7) Perceived safety and driver acceptance.
Quality: High
Quality Note:
Applicability: Med-High
Applicability Note: Passenger vehicle only, but there are a number of relevant methodological lessons learned.
Key Findings and Recommendations: - Many alerts were perceived to be unnecessary by drivers. - Increased headways with FCW enabled - In some instances, the FCW device may have helped the drivers avoid a crash - The drivers tended to "experiment" with the system over a long period of time. - Individual differences, such as driving style, mileage associated with an individual, and the road types and traffic conditions associated with a driver's testing time had a large influence on the data.
Caveats/Comments: The collection of baseline driving data for one week was very helpful to subsequent analysis. This seems to be the same study as reported in General Motors, 2005.

Document:
General Motors. (2005). *Automotive collision avoidance system field operational test final program report.* (Report No. DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.

Safety System:
FCWS

Vehicle Type:
Passenger Vehicles

Study Type:
Field Test

General Approach:
96 participants drove in vehicles equipped with Automotive Collision Avoidance Systems (ACAS), consisting of FCWS-ACC, to determine the effects of using the ACAS on driver performance. Each participant drove without the ACAS for one week and then with the ACAS for 3-4 weeks.

Measures of Effectiveness:
1) Driving distances/ headways.
2) Driver response to emerging rear-end conflicts.
3) Questionnaire, interview, focus group data.

Quality:
High

Quality Note:
Methodology was thoroughly developed, tested, refined, and implemented to produce a high quality and immense (1.4 Terabytes) set of data.

Applicability:
Low-Medium

Applicability Note:
The report focuses on the overall effects on driver performance and safety when using ACC, but few of the results are directly attributed to system components/features.

Key Findings and Recommendations:
Overall, the ACAS System as implemented was effective at promoting safe driving behavior and increasing awareness of potential conflicts.

- *Nuisance Alarms:*
  - The majority of alerts were perceived to have been either unnecessary or a nuisance, fostering poor driver acceptance and trust. Only 27 percent of all imminent alerts were triggered by events requiring driver intervention to resolve a developing conflict.
  - Since drivers became aware that the FCW alerts often occurred in situations in which braking was not required, they did not brake reflexively to imminent FCW alerts.
  - Although drivers could adjust the sensitivity of the cautionary alert even to a lowest setting that suppresses the cautionary icons altogether, many drivers retained sensitivity settings that yielded cautionary alerts during 9 percent of the time the FCW was in use.
- *Usage of ACC Headway-Gap and Max-Deceleration Braking Settings:*
  - Although the ACC was capable of automatically decelerating at up to 0.3 g, the deliberately retarded delivery of this response by the ACC controller is believed to have discouraged drivers from depending on it.
- *Driver Acceptance:*
  - Driver acceptance results were mixed; less than half of the drivers indicated an interest in purchasing the system. The high false alarm rate clearly decreased driver acceptance.

Caveats/Comments:

This seems to be the same study as reported in Ervin et al., 2005.

Document: General Motors & Delphi-Delco Electronic Systems. (2002). *Automotive Collision Avoidance System Field Operation Test, Warning Cue Implementation Summary Report* (DOT HS 809 462). Washington, DC: National Highway Traffic Safety Administration.
Safety System: FCWS
Vehicle Type: Passenger Vehicle
Study Type: Driving Simulator Study
General Approach: 80 participants drove a driving simulator following a lead vehicle. Participants responded to LV brake events, cued by different types of forward collision warning (FCW) display types. In a second experiment, twelve drivers experienced four display candidates in the driving simulator and answered questions regarding preference and annoyance.
Measures of Effectiveness: 1) Headway 2) Response time to an unexpected lead-vehicle braking event.
Quality: Medium
Quality Note: Sound approach but used statistical control for differences in head way at time of deceleration event (see caveats).
Applicability: Low-Medium
Applicability Note: Focus was on display design, not really broader system effectiveness
Key Findings and Recommendations: - Display type did not affect headway time or head-way time variance. - All displays except the one-stage and scale displays were significantly faster than control (no display). - Looming and 2-stage displays had the fastest Brake RT’s and also required less deceleration. - Looming displays were rated as being most understandable, attention getting, and most preferred. - Overall, there was no benefit of adding either scale information or more than two levels of warning to the displays. - There was no additional benefit of auditory or seat-vibration cues (the seat vibration was only noticed by 2/10 participants). - The results of a second experiment generally confirmed the looming displays were rated as being most understandable, attention getting, and most preferred.
Caveats/Comments: - Didn’t control for headway before the deceleration event, so headway accounted for 68% of the Brake RT variance, which necessitated using an ANCOVA for controlling for the effects of headway.

Document: Groeger, J. A. (1998). Close, but no cigar: Assessment of a headway warning device. IEE Colloquium on Automotive Radar and Navigation Techniques, 5-1 - 5/4.
Safety System: FCWS
Vehicle Type: Passenger Vehicle
Study Type: On-road study
General Approach: 32 drivers drove a 22.5 mile route in and around Cambridge, England. The route included urban, rural, and motorway sections with varying speed limits from 30–70 mi/h. The drivers were divided into a warning group and a control group. Drivers in the warning group received auditory warnings when their headway reached 1 second or less for 0.5 seconds.
Measures of Effectiveness: 1) Time headway
Quality: Low-Medium
Quality Note: Individual driver performance could not be compared across conditions. Data integration was incomplete across conditions.
Applicability: Low-Medium
Applicability Note:
Key Findings and Recommendations: - Drivers in the control group held consistent average time headways regardless of speed. - Warnings reduced the occurrence of critically short time headways (<1 second). - The number of critically short time headways increased with speed, however the reduction of these critically short headways through the use of warnings was larger in higher speed zones. - Trucks were followed more closely than cars. - Warnings did not consistently reduce the time headway when following cars, but they did when following larger trucks.
Caveats/Comments: None

Document:
Kiefer, R. J., Cassar, M. T., Flannagan, C. A., Leblanc, D. J., Palmer, M. D., Deering, R. K., & Shulman, M. A. (2003). *Forward Collision Warning Requirements Project: Refining the CAMP Crash Alert Timing Approach by Examining "Last-Second" Braking and Lane Change Maneuvers Under Various Kinematic Conditions.* (Report No. DOR HS 809 574). Washington, DC: National Highway Traffic Safety Administration.

Safety System:
FCWS

Vehicle Type:
Passenger

Study Type:
Test Track

General Approach:
In a field study, drivers performed last-second braking maneuvers using two different braking instructions: 1) maintain speed and brake at the last second possible in order to avoid a crash using **normal** braking, and 2) maintain speed and brake at the last second possible in order to avoid a crash using **hard** braking. Similar instructions were given for steering responses to the collision event.

Measures of Effectiveness:
1) Last-second braking and steering behaviors.

Quality:
High

Quality Note:

Applicability:
Low

Applicability Note:
Very limited applicability: conducted on a test track with researchers in the test vehicle. The focus was not so much on system effectiveness as on system design (alert timing).

Key Findings and Recommendations:

- The relative timing of drivers' responses was highly dependent on the kinematics of the situation.
- Separate models were derived from the data – driver deceleration response is based in an inverse TTC threshold that decreases linearly with speed.

Caveats/Comments:

This was a follow-on to earlier CAMP work. The emphasis here was on examining fine-grained driver performance once an alert has been issued.

Document: Gish, K. W., Mercadante, M., Perel, M., & Barickman, F. (2002). The effect of false forward collision warnings on driver responses. *Proceedings of the Transportation Research Board 81st Annual Meeting.*
Safety System: FCWS
Vehicle Type: Passenger vehicles
Study Type: Field Study
General Approach: To determine the effect of false FCWs on driver responses, 16 drivers were presented with correct warnings and false warnings while driving along a pre-defined route on public roads. On all correct warning trials and half of the false warning trials, drivers were distracted by a speed monitoring task when the warnings were presented.
Measures of Effectiveness: 1) Driver behavior: response times, braking/deceleration rates. 2) Secondary task response times.
Quality: Low-Medium
Quality Note: While methodology is generally sound, test conditions may not fully apply to naturalistic driving in a non-test environment.
Applicability: Low-Medium
Applicability Note: The focus of the study was on overall effects on driver performance of false warnings and does not address methods for reducing the occurrence of false warnings. Broader system effectiveness topics are not addressed.
Key Findings and Recommendations: - *Distraction and Exposure Effects:* o Undistracted drivers stopped responding to false warnings after only a few exposures. o When the same drivers received false warnings while distracted, drivers continued to respond to false warnings regardless of prior false warning exposures. o No evidence was found to suggest any response inhibition to correct warnings after repeated exposure to false warnings. - *Braking and Speed Reduction Behavior:* o Drivers brake in response to false warnings. o Mean braking RT on undistracted FW trials ranged from 2 to 3.5 seconds, and the total number of brake responses decreased monotonically with successive exposures. o Brake reaction times during DCW trials were typically less than 2 seconds. o Approximately 25% of combined FW and DFW trials resulted in false alarm reactions (brake RT was <2 seconds). o Mean deceleration for combined FW and DFW trials was 0.05g compared to 0.1g for DCW trials.
Caveats/Comments: - Distraction Only trials are those in which only the in-vehicle distracter task was being performed by the driver during the trial. - Because the study required real on-road driving conditions, the trials were designed to minimize the risk of a collision with the conflict vehicle, reducing the level of threat felt by the driver. Therefore, the collision warning algorithm and subsequent scenario timings may be more relaxed than would be in a non-test environment.

Document:
Jamson, A. H., Lai, F. C. H., & Carsten, O. M. J. (2008). Potential benefits of an adaptive forward collision warning system. Transportation Research Part C: Emerging Technologies, 16(4), 471-484.

Safety System:
FCWS

Vehicle Type:
Passenger Vehicle

Study Type:
Driving simulator study

General Approach:
Forty-five experienced simulator drivers participated in the experiment. Adaptive FCW (using driver's actual brake reaction time), non-adaptive FCW (1.5s fixed reaction time), and baseline data were collected for six expected and one unexpected braking events. Questionnaires collected user acceptance data after the three trials.

Measures of Effectiveness:
1) Brake reaction time: time between lead vehicle brake light illumination and brake pedal pressure.
2) Minimum headway.
3) Self-report data on FCW.
   a. Alarm timing and frequency.
   b. Mental effort of use.
   c. User acceptance of warnings.
   d. Trust in the system.
   e. Personal factors: safety, irritation, stress, feeling of being controlled, joy of driving, attentiveness in traffic.

Quality:
High

Quality Note:

Applicability:
Medium

Applicability Note:
The research was performed on a simulator, using passenger cars in a rural setting. It provides an interesting case for adaptive FCWS and inclusion of personal characteristics.

Key Findings and Recommendations:
- Long followers (preferred time headway over the median value) had consistent brake reaction times regardless of the system used.
- Short followers had shorter brake reaction times with the non-adaptive system than in baseline conditions, and even shorter reaction times with the adaptive system.
- Drivers without an FCW had shorter minimum headways than those with the systems (but no difference between the systems).
- High sensation seekers had shorter minimum headways than low sensation seekers.
- Drivers felt that alarms occurred too early with both systems, but the adaptive system providing more appropriately timed alarms and alarms with improved frequency.
- Short followers rated the mental effort higher than long followers.
- Both systems were rated positively for usefulness, but less than satisfactory.
- High sensation seekers preferred the adaptive system with regards to user acceptance and system trust.
- High sensation seekers, short followers, and fast reactors became more irritated with FCW than low sensation seekers, long followers, and slow reactors.

Caveats/Comments:
- System trust was evaluated using a perfectly functioning FCWS with no false alarms.
- Participant irritation may have been affected by the frequency of braking events in the study, which was greater than that of most real world scenarios.

Document: Leblanc, D. J., Bareket, Z., Ervin, R. D., & Fancher, P. (2002). Scenario-Based Analysis of Forward Crash Warning System Performance in Naturalistic Driving. *Proceedings of the 9th World Congress on Intelligent Transport Systems,* 12p.
Safety System: FCWS
Vehicle Type: Passenger Vehicle
Study Type: Field Study
General Approach: Used empirical data obtained from the research team to examine the utility of a scenario-based analysis of system performance; i.e., what kinds of driving scenarios are associated with crash alerts and what estimates did drivers provide of the alert's utility?
Measures of Effectiveness: 1) Post drive estimates of FCW alert utility (i.e., useful, nuisance, missing/late, and other- would have been useful had the driver been inattentive. 2) Frequency of alerts as a function of various alert scenarios. There were 13 scenarios total organized broadly into 3 categories: 1) both vehicles in same lane throughout scenario, 2) at least one vehicle changing lanes during the scenario, 3) alerts triggered by stationary roadside objects.
Quality: Medium
Quality Note: The study was exploratory in nature, though it was well-conceived and well-executed. The use of knowledgeable researchers as subjects is consistent with the exploratory nature of the study; however, the results may not be representative typical drivers' experiences or reactions.
Applicability: Medium - High
Applicability Note: The fine-grained approach to obtaining drivers' estimates of utility is a useful framework, though implementing this in a true field study would be problematic. The notion that efficacy can vary across driving scenarios is also very useful.
Key Findings and Recommendations: - The scenario-based approach may be a useful tool in the design and evaluation of FCW systems. - The relative frequency of alerts across scenarios indicates the relative value of the FCW in those scenarios (as well as the value of improving the system for those scenarios). - FCW experience may be different across different roadways.
Caveats/Comments: None.

Document: Kiefer, R. J., Cassar, M. T., Flannagan, C. A., Jerome, C. J., & Palmer, M. D. (2005). Surprise braking trials, time-to-collision judgments, and "first look" maneuvers under realistic rear-end crash scenarios. (Report No. DOT HS 809 902). Washington, DC: National Highway Traffic Safety Administration.
Safety System: FCWS
Vehicle Type: Passenger Vehicles
Study Type: Closed-track Study
General Approach: 260 participants drove an FCW-equipped vehicle on a closed-course test road and followed a vehicle mock-up towed by a POV. Drivers were untrained with the FCW system (and unaware of its presence) and had to respond to a single LV braking event that they were not expecting.
Measures of Effectiveness: 1) Experimenter Brake Assists. 2) Driver Brake Reaction Time (RT), 3) Required Deceleration Level. 4) Time-To-Collision. 5) Time Headway At POV Brake Onset, & Peak Deceleration. 6) Subjective ratings of Alert Noticeability.
Quality: High
Quality Note: This research involves a comprehensive look at many factors that influence potential system effectiveness.
Applicability: Medium
Applicability Note: Investigated key FCW concepts using realistic on-road driving conditions. The investigation focused on micro-aspects of driver behavior, rather than on broader issues of crash reduction.
Key Findings and Recommendations: - Based on test driver intervention rates (crash surrogates) during surprise trials, the alert timing approach evaluated, coupled with a single-stage, dual-modality (auditory plus visual) FCW alert, was found to be robust, effective, and judged appropriate across the wide range of conditions evaluated. It also lead to an improvement (safer values) in all dependent variables except time headway. - With the distracted drivers, 99% of the auditory alerts were noticed by participants, while only 17-50% of visual alerts were noticed. - The 2-stage warning was less effective (first stage was visual-only alert presented when driver was distracted). - The CAMP auditory alert was more effective than a "friendlier" alert sound. - The benefits of the FCW alerts were diminished by high false alarm rates. - The benefits of the FCW alert during surprise trials were restricted to tasks involving head-down glance activity and were not evident for the eyes-forward distraction tasks examined. - Across all the actual FCW alert conditions examined, there is generally a lack of both age and gender effects when the FCW system is used, while there are differences without the system. This suggests that FCW alerts may be an effective means of equalizing a driver's abilities to avoid rear-end crashes.
Caveats/Comments: - Two other studies that examined TTC perception were conducted in this report but not reported here.

Document: Murray, D., Shackelford, S., & Houser, A. (2009). *Analysis of Benefits and Costs of Forward Collision Warning Systems for the Trucking Industry*. (Report No. FMCSA-RRT-09-021). Washington, DC: Federal Motor Carrier Safety Administration.
Safety System: FCWS
Vehicle Type: Heavy Trucks
Study Type: Analysis – costs and benefits associated with FCWS
General Approach: Data from insurance companies and motor carriers were obtained to examine the number of crashes that FCW devices could prevent as a function of vehicle miles traveled. Then, total costs associated with crashes, labor, workers' compensation, operational, property damage, environmental damage, legal, etc. were calculated to generate an estimate of cost savings associated with the installation of FCW devices.
Measures of Effectiveness: 1) Crashes preventable by FCWS.
Quality: High
Quality Note:
Applicability: Medium
Applicability Note: Crashes are important, but since they are so rare, estimating the number of crashes that FCW devices could prevent is an inexact process.
Key Findings and Recommendations: - Direct, out of pocket costs for crashes are $122, 650, $239,063, and $1,056,221 for PDO (Property Damage Only) crashes, injury crashes and fatal crashes, respectively. - Motor carriers with a typical likelihood of being involved in a rear-end crash will achieve positive returns on investment with FCW devices.
Caveats/Comments: - This kind of cost-benefit analysis is an important element of an overall effort to understand the value of FCW devices. In addition to crashes, other MOEs should be evaluated. - As noted above, the data used in this analysis were obtained from insurance companies and motor carriers; the reliability & accuracy of the underlying data are uncertain.

Document: Kiefer, R. J., Cassar, M. T., Flannagan, C. A., Leblanc, D. J., Palmer, M. D., Deering, R. K., et al. (2003). *Forward collision warning requirements project: Refining the CAMP crash alert timing approach by examining "last-second" braking and lane change maneuvers under various kinematic conditions.* (Report No. DOR HS 809 574). Washington, DC: National Highway Traffic Safety Administration.
Safety System: FCWS
Vehicle Type: Passenger
Study Type: Test Track
General Approach: In a field study, drivers performed last-second braking maneuvers using 2 different braking instructions: 1) maintain speed and brake at the last second possible in order to avoid a crash using **normal** braking, and 2) maintain speed and brake at the last second possible in order to avoid a crash using **hard** braking. Similar instructions were given for steering responses to the collision event.
Measures of Effectiveness: 1) Last-second braking and steering behaviors.
Quality: High
Quality Note:
Applicability: Low
Applicability Note: Very limited applicability: conducted on a test track with researchers in the test vehicle. The focus was not so much on system effectiveness as on system design (alert timing).
Key Findings and Recommendations: - The relative timing of drivers' responses was highly dependent on the kinematics of the situation. - Separate models were derived from the data—driver deceleration response is based in an inverse TTC threshold that decreases linearly with speed.
Caveats/Comments: This was a follow-on to earlier CAMP work. The emphasis here was on examining fine-grained driver performance once an alert has been issued.

Document:
Kiefer, R., Leblanc, D., Palmer, M., Salinger, J., Deering, R., & Shulman, M. (1999). *Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems.* (Report No. DOT HS 808 964). Washington, DC: National Highway Traffic Safety Administration.

Safety System:
FCWS

Vehicle Type:
Passenger Vehicles

Study Type:
Design Guidelines/Standards

General Approach:
A set of 40 preliminary human factors guidelines/goals was developed for designing an FCW system.

Measures of Effectiveness:
N/A.

Quality:
High

Quality Note:
The guidelines are based on high-quality data and thorough methodology.

Applicability:
Low

Applicability Note:
The focus of this research is directed toward the development of FCW systems and presents developed guidelines for a variety of relevant topics.

Key Findings and Recommendations:
This document presents 40 preliminary functional requirements for addressing the following topics:

- *DVI:*
  - 13 requirements including single- vs. multi-stage FCW warnings, crash warning timing and control of timing, warning modality, auditory warning characteristics, visual warnings characteristics, indication of system status.
- *Warning Zone Timing:*
  - 7 requirements including general criteria, “too early”, “too late”, POV encroachment, immediacy of warning due to changing situation.
- *Warning Zone Boundaries:*
  - 9 requirements including vertical and longitudinal extent of warning zone, proximity and dimensions of warning zone relative to SV, roadway curvature.
- *Environment around the Warning Zone:*
  - 11 requirements including weather, time of day/lighting conditions, sight distance, recognition of small vehicles (e.g., motorcycles), valid activation vs. nuisance warnings, acceptable nuisance warning rates, reduction of nuisance warnings.

Caveats/Comments:

- This review represents Chapter 4 of the “Preliminary Minimum Functional Requirements and Recommendations” report. Chapter 3 of the overall document contains the human factors data from which these guidelines are produced.
- The requirements produced in this effort are preliminary; further evaluation of these requirements under in-traffic, operational field test, and vehicle-level testing conditions is recommended by the authors.
- Tables summarizing the requirements are included at the end of the report.

Document:
McGehee, D. V., Brown, T. L., Lee, J. D., & Wilson, T. B. (2002). Effect of warning timing on collision avoidance behavior in a stationary lead vehicle scenario. *Transportation Research Record, 1803*, 1-7.

Safety System:
FCWS

Vehicle Type:
Passenger Vehicle

Study Type:
Driving simulator study

General Approach:
30 drivers aged 18-24 participated in the study. A baseline condition and two collision warning types (early and late) were assessed. The warning displays were an auditory car horn and a mounted head-down headway display. Drivers were given a distracter task immediately before a stationary lead vehicle appeared.

Measures of Effectiveness:
1) Impact with the lead vehicle.
2) Speed on impact.
3) Time to collision (TTC)—defined at 6 points during breaking after observing the stationary lead vehicle.
4) Transition time between accelerator release and brake input.
5) Mean response time.
6) Maximum brake pressure input.
7) Maximum steering input—greatest steering wheel movement in either direction.
8) Maximum lateral acceleration—provided a pattern similar to maximum steering input, but measured the severity of steering input.

Quality:
Medium

Quality Note:
Drivers were split into 3 groups of 10 drivers for each condition: baseline, early warning, and late warning. Individual driver performance could not be compared across conditions.

Applicability:
Medium

Applicability Note:
The study was conducted on a simulator using a passenger vehicle. Although it only used one scenario, the proportion of rear-end collisions that involve a stationary lead vehicle is high.

Key Findings and Recommendations:

- With early warning conditions compared to baseline conditions:
    - Drivers responded quicker.
    - Drivers had a greater TTC at initial and final accelerator release.
    - Drivers experienced fewer collisions (1 vs. 3) and a slower mean speed at impact (19 vs. 37.9 mi/h).
- Overall seven out of the nine total collisions occurred when drivers applied the brakes without swerving. Four of the non-swerving collisions occurred in the late warning condition, perhaps indicating that the late warning interferes with response formulation.
- Results support previous findings that drivers must be able to perceive the lead vehicle when the warning is issued in order for it to be effective.

Caveats/Comments:
None

Document: Murray, D., Shackelford, S., & Houser, A. (2009). *Analysis of benefits and costs of forward collision warning systems for the trucking industry*. (Report No. FMCSA-RRT-09-021). Washington, DC: Federal Motor Carrier Safety Administration.
Safety System: FCWS
Vehicle Type: Heavy Trucks
Study Type: Analysis—costs and benefits associated with FCWS.
General Approach: Data from insurance companies and motor carriers were obtained to examine the number of crashes that FCW devices could prevent as a function of vehicle miles traveled. Then, total costs associated with crashes, labor, workers' compensation, operational, property damage, environmental damage, legal, etc. were calculated to generate an estimate of cost savings associated with the installation of FCW devices.
Measures of Effectiveness: 1) Crashes preventable by FCWS
Quality: High
Quality Note:
Applicability: Medium
Applicability Note: Crashes are important, but since they are so rare, estimating the number of crashes that FCW devices could prevent is an inexact process.
Key Findings and Recommendations: - Direct, out of pocket costs for crashes are $122, 650, $239,063, and $1,056,221 for PDO (Property Damage Only) crashes, injury crashes and fatal crashes, respectively. - Motor carriers with a typical likelihood of being involved in a rear-end crash will achieve positive returns on investment with FCW devices.
Caveats/Comments: - This kind of cost-benefit analysis is an important element of an overall effort to understand the value of FCW devices. In addition to crashes, other MOEs should be evaluated. - As noted above, the data used in this analysis were obtained from insurance companies and motor carriers; the reliability & accuracy of the underlying data are uncertain.

Document: Najm, W. G., Stearns, M. D., Howarth, H., Koopmann, J., & Hitz, J. (2006). *Evaluation of an Automotive Rear-End Collision Avoidance System.* (Report No. DOT-VNTSC-NHTSA-06-01. HS-810 569). Research and Innovative Technology Administration. Volpe National Transportation Systems Center. National Highway Traffic Safety Administration.
Safety System: FCWS
Vehicle Type: Passenger Vehicle
Study Type: Field Study—FOT
General Approach: A safety benefits analysis was conducted as an independent evaluation of UMTROs ACAS FOT. The system's ability to reduce the drivers' exposure to lead-vehicle accelerating or lead-vehicle stopped conflicts was examined. Thus, the system's efficacy in reducing rear-end crashes was the key outcome variable. Driver acceptance topics were also examined.
Measures of Effectiveness: 1) Changes in the drivers' exposure to lead-vehicle accelerating or lead-vehicle stopped conflicts. 2) Changes in rear-end crashes. 3) Driver acceptance: ease of use, ease of learning, perceived value, advocacy, driving performance.
Quality: High
Quality Note:
Applicability: High
Applicability Note:
Key Findings and Recommendations: - ACAS has the ability to prevent about 10% of all rear-end crashes (specifically, somewhere between 3% and 17%). - Driver acceptance data were mixed; when the system warned drivers of actual threats, their opinion was positive. False/nuisance alarms were a problem; 41% of the subject would have used an on-off switch, had one been available.
Caveats/Comments: This is an independent evaluation of UMTRI's ACAS FOT.

Document: Ravani, B., Yen, K. S., Tan, H.-S., Steinfeld, A., Thorne, C. H., Bougler, B., et al. (1999). *Advanced snowplow development and demonstration : Phase I: Driver assistance.* (Report No. UCD-ARR-99-06-30-33). Davis: University of California, Advanced Highway Maintenance and Construction Technology Center.
Safety System: FCWS
Vehicle Type: Snowplow
Study Type: Field Study (on test bed)
General Approach: The snowplow system included a lane departure component as well as FCWS.
Measures of Effectiveness: 1) Safety Measures: accidents and injuries. 2) Ride-alongs: qualitative assessment of the system's efficiency. 3) Traveler mobility: number of road closures. 4) Technology performance: number of system failures. 5) Telephone interviews: overall impressions, assessment of system components, failures or errors, recommendations for changes to the system.
Quality: Low
Quality Note: This was a very short study; little before/after evaluation.
Applicability: Med.
Applicability Note: Despite the incomplete data, the intended MOEs reflected a useful mix of quantitative and qualitative measures, with a focus on before/after measurements. The exact measures used will be different for OBSSs in heavy trucks, but the measures used here may have some relevant parallels.
Key Findings and Recommendations: - The short timeline did not allow for sufficient data to be collected. - Lots of recommendations for improving the human-machine interface (HMI).
Caveats/Comments: This looks like the same project as: Cuelho, E. (2000). An Evaluation of Intelligent Vehicle Technologies on Rural Snowplows. *Proceedings of the ITS 10th Annual America Meeting*, 0030.pdf.

Document: Zhang, W.-B., Shladover, S. E., & Zhang, Y. (2007). Evaluation of forward collision warning system for urban driving. *Transportation Research Record, 2000*, 106-113.
Safety System: FCWS
Vehicle Type: Transit Bus
Study Type: Field Study – Field Operational Test
General Approach: 2 transit buses in San Mateo County, CA were equipped with the FCWS for approximately 11 months. The routes included one-and two-lane local streets and freeways, with flat and steep sections. Baseline data was collected and data from the 7 drivers with the most experience on the instrumented buses was analyzed.
Measures of Effectiveness: 1) Car-following time gap. 2) Brake pressure. 3) Longitudinal acceleration and deceleration. 4) Time to collision (TTC). 5) Required deceleration—the minimum amount of deceleration necessary to avoid a collision.
Quality: Medium
Quality Note: Small sample size of drivers caused individual driver behaviors to show in the data
Applicability: Medium
Applicability Note: The data applies to FCWS, but more specifically to urban bus routes which require the drivers to get in close proximity to parked vehicles, curbs, etc.
Key Findings and Recommendations: - FCWS led to more consistent and generally safer driving behaviors. - Individual driver differences were most noticeable in the car-following time gaps. - Drivers showed different preferences for sensitivity levels when the adjustment was made available to them.
Caveats/Comments: - During the verification tests, erroneous lateral measurements to targets were observed, potentially causing false alarms during the field testing. No surveys were conducted to check this effect with the operators; however, the sensitivity of the FCWS was adjustable. False alarms could not be identified quantitatively from the data.

LDW REVIEWS

Document: Battelle. (2003). *White Paper: Mn/Dot Driver Acceptance: IVI FOT Evaluation Report.* (Report No. FHWA-OP-03-182). Washington, DC: Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems.
Safety System: LDWS
Vehicle Type: Specialty Vehicle (snowplow, ambulance, state patrol car)
Study Type: Field Test
General Approach: Before and after Internet surveys and in-person interviews were administered to 25 drivers and 3 supervisors. For three months participants drove vehicles equipped with a CWS that included a GPS-based lane departure warning system with visual, auditory, and haptic alarms.
Measures of Effectiveness: 1) Driver perception of usefulness. 2) Driving behavior. 3) Perceived mental workload. 4) Perceived liability.
Quality: High
Quality Note:
Applicability: Med
Applicability Note: Not directly related to heavy vehicles. No objective MOEs.
Key Findings and Recommendations: - *Driver perception of usefulness:* o Drivers reported reduced agreement with potential benefits, greater concerns with the technology interference with the driving task, and increased distraction and effort associated with the use of the technology, compared with their initial expectations in the first survey. - *Driving behavior:* o 70 percent of respondents said the LDWS did not change their driving behavior. o Drivers interviewed in person thought the safety technologies would make them more alert, more relaxed and probably more careful about safely managing driving tasks. - *Perceived mental workload:* o On average, drivers indicated that the level of mental workload was reduced by using the technologies. o Actual workload reduction experienced by drivers was half of the expected workload reduction noted in the initial survey. - *Perceived liability:* o 38 percent of ambulance and snowplow drivers agreed that the CWS provided safety benefit, while 38 percent of these drivers disagreed. o Ambulance operators said they were reluctant to use the CWS when a patient's life was at risk in an emergency driving situation.
Caveats/Comments: Some of the results were related to the CWS as a whole and not the LDWS alone.

Document: Hadi, M. A., Sinha, P. K., & Easterling, J. R., IV. (2007). Effect of environmental conditions on performance of image recognition-based lane departure warning system. *Transportation Research Record, 2000*, 114-120.
Safety System: LDWS
Vehicle Type: Light Truck
Study Type: Field Test
General Approach: A pickup truck equipped with a vision-based LDWS was driven a total of 200 miles on the Florida Turnpike in four levels of precipitation: dry, light rain, moderate rain, and heavy rain. The driver intentionally crossed the left and right edge lines to determine how many times the LDWS actuated a warning.
Measures of Effectiveness: 1) Efficacy Rating (ER): ratio of the number of alerts to the number of lane departures. 2) Number of false alerts per mile that occur when the vehicle does not cross the lane markings.
Quality: Medium
Quality Note: Solid research but does not consider roads with old or worn pavement markings; the results may not be generalizable to all roads.
Applicability: Low
Applicability Note: Indirectly relates to effectiveness of LDWS on driving behavior: the research measures the LDWS system performance rather than the effectiveness of the LDWS in affecting driver behavior.
Key Findings and Recommendations: - *Efficacy Rating:* o In most cases, the ER of the LDWS was 100% for dry and light rain conditions (i.e., each lane departure produced an alert). o Moderate rain resulted in ER of 60% to 80% until the road markings because completely covered with water. Once the markings were covered, the ER dropped to as low as 0% to 20%. o Heavy rain at night reduced the ER to between 0% and 30%. o Blinding rain conditions during daylight reduced ER by only 20%. o Dusk conditions reduced ER by 15% to 18%. - *False Alarms:* o Under daylight conditions, zero false alarms occurred in dry, light rain, and moderate rain; and between 0.5 and 1 false alarms per mile occurred in heavy rain. o No false alarms occurred during glaring dusk conditions. o No false alarms occurred during dry or light rain conditions at night.
Caveats/Comments: - Retroreflectivity of almost all lane markings were greater than Florida DOT’s minimum. - The research was performed in support of the IVBSS initiative.

Document:
Ho, A., Cummings, M. L., Kochhar, D. S., Tijerina, L., & Wang, E. (2006). Integrating Intelligent Driver Warning Systems: Effects of Multiple Alarms and Distraction on Driver Performance. *Proceedings of the Transportation Research Board 85th Annual Meeting*.

Safety System:
LDW (part of overall CWS with FCW and FVFA*)

Vehicle Type:
Passenger Vehicle

Study Type:
Driving Simulator

General Approach:
40 drivers experienced FCW, FVFA, and LDW auditory warnings of varying levels of reliability while driving. One half of drivers heard the same master alarm for all warnings, and one half heard warning alerts that were distinct for each type of warning. Unique LDW warnings consisted of a localized, low frequency rumble strip.

Measures of Effectiveness:
1) Reaction time.
2) Response Accuracy.
3) Subjective participant ratings.

Quality:
Med

Quality Note:
MOEs not directly measured in real-world conditions.

Applicability:
Med

Applicability Note:
Not directly related to heavy vehicles, but MOEs may be applicable to HVs.

Key Findings and Recommendations:
- *Reaction Time:*
  - There were no significant differences in reaction times when comparing single versus multiple alarms for the different driver warning systems.
  - Response times were similarly short for both high and low reliability LDW warnings.
- *Response Accuracy:*
  - There were no significant differences in response accuracy when comparing single versus multiple alarms for the different driver warning systems.
  - Responses were significantly more accurate when the warnings were highly reliable.
- *Subjective participant ratings:*
  - Participants preferred distinct alarms for different driver warning systems.

Caveats/Comments:
*FVFA—Following-Vehicle Fast Approach.
Auditory warning localization may not be effective in a heavy truck environment due to ambient noise in the cab.

Document: Houser, A., Murray, D., Shackelford, S., Kreeb, R., & Dunn, T. (2009). *Analysis of benefits and costs of lane departure warning systems for the trucking industry* (FMCSA-RRT-09-022). Washington, DC: Federal Motor Carrier Safety Administration.
Safety System: LDWS
Vehicle Type: Heavy Truck
Study Type: Analytical Study / Crash Data Analysis
General Approach: Estimated savings associated with crash reductions from LDWS for straight and combination trucks were compared against purchase, installation, and operating costs, to evaluate relative costs and benefits associated with LDWS for the trucking industry. Costs were calculated for Property-Damage-Only, Injury, and Fatal crashes based on crash rates obtained from GES data.
Measures of Effectiveness: 1) Cost Effectiveness for Motor Carriers.
Quality: High
Quality Note:
Applicability: Med-High
Applicability Note: Useful information about an indirect MOE, however, performance/safety data are taken from other studies.
Key Findings and Recommendations: System efficacy rates were taken from field studies and industry input. A maximum of 53% and a minimum of 23% crash prevention efficacy was assumed for the analysis. Annual crash reduction from LDWS were estimated at 1,069-4,463 for SVRD collisions, 627-1,307 for SVRD rollovers, 1,111-2,223 for SDLD sideswipes, 997-1,992 for ODLD sideswipes, and 59-118 ODLD for head-on collisions. *Cost Effectiveness* Total motor carrier deployment costs were estimated at $765-$866.40 per vehicle. The range of estimated average direct “out-of-pocket” costs across the various crash types for each crash severity type was: ▪ PDO: $100K-196K. ▪ Injury: $135K-455K. ▪ Fatal: $896K-1,252K. Regardless of VMTs, medium-sized to large carriers with an average likelihood of lane departure crashes will achieve positive investment returns. Range of the positive return was $1.37 to $6.55 for each dollar spent, depending on cost assumptions. Small carriers that have low insurance deductibles (with costs primarily covered by insurance) may not achieve direct cost recovery in the first five years. However, the lower long-term insurance rates and other less-tangible benefits (e.g., safety record) make LDWS worth considering.
Caveats/Comments: None.

Document: LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, S., et al. (2006). *Road departure crash warning field operational test. Volume 1: Technical report.* (Report No. UMTRI-2006-9-1). Ann Arbor: University of Michigan Transportation Research Institute.
Safety System: LDWS
Vehicle Type: Passenger Vehicle
Study Type: Field Test
General Approach: 78 drivers performed naturalistic driving for four weeks in vehicles equipped with LDW and CSW. In the first week, no warnings were presented.
Measures of Effectiveness: 1) Number of lane changes without turn signal. 2) Turn signal use per unit distance traveled. 3) Lane keeping. 4) Number of lane excursions. 5) Time spent in lane excursions. 6) Subjective ratings.
Quality: High
Quality Note:
Applicability: Med
Applicability Note: Related to passengers vehicles.
Key Findings and Recommendations: - *Number of lane changes without turn signal:* o Decreased by 43 percent on freeways and by 24 percent on surface roads. - *Turn signal use per unit distance traveled:* o Increased by 9 percent overall with 23 percent increase in the quartile of drivers with the lowest initial rates of turn signal applications per unit distance. - *Lane Keeping: Standard deviation of lane position:* o The standard deviation of lane position decreased when the RDCW was enabled. - *Number of lane excursions:* Number of events in which the outside of the tire came within four inches of the lane edge o Number of lane excursions was reduced by 50 percent. - *Time spent in lane excursions:* The time spent within four inches of the lane edge or outside the lane edge o Time spent in lane excursions was reduced by 63 percent. - *Subjective ratings:* o Drivers reported that 75 percent of LDW warnings were useful. Drivers reported that they used cell phone less often and turn signals more often when LDW was enabled. Drivers infrequently reported concerns regarding false alerts from LDW.
Caveats/Comments: - Some results are reported as effects of the overall RDCW and were not attributed to LDWS alone. - Although the research included passenger vehicles, the same principles that drive the current results may also apply to heavy vehicles (e.g., increased turn signal use to avoid false alarms). However some results may not be applicable to heavy vehicles. For example, the vibrating seat haptic display may not be effective in HV because of the vibrations may be difficult to distinguish from existing ambient vibrations in the cab.

Document: Rimini-Doering, M., Altmueller, T., Ladstaetter, U., & Rossmeier, M. (2005). Effects of lane departure warning on drowsy drivers' performance and state in a simulator. *Proceedings of Driving Assessment 2005: 3rd International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design,* 88-95.
Safety System: LDW
Vehicle Type: Passenger Vehicle
Study Type: Driving Simulator Study
General Approach: 63 younger males drove in a stimuli-deprived simulator scenario for 2.5 hours after a rich meal to induce drowsiness. Approximately one third of participants were assisted by LDWS. Physiological measures (PERCLOS, saccades, heart rate, etc. EEG/EMG/EDA, etc.) were collected in concert with driving behavior in order to fully characterize lane departure events.
Measures of Effectiveness: 1) Number of lane departure events (LDE). 2) Duration of lane departure. 3) Magnitude of lane departure.
Quality: Medium
Quality Note: Solid research but does not examine effects in a real-world environment.
Applicability: Medium
Applicability Note: Although the research is relevant to light vehicles, it provides MOEs that are applicable to Heavy Vehicles.
Key Findings and Recommendations: - *Number of lane departure events (LDE):* o LDWS assisted drivers experienced an average of approximately 10 lane departure events, compared to 20 LDEs for drivers without LDWS. o 215 LDWs were issued, with only 25 LDEs occurring after receiving warnings. - *Duration of lane departure:* o Drivers with LDWS spent 20% less time out of lane during lane departures compared to drivers without LDWS. - *Magnitude of lane departure* o Magnitude of lane departure was 36% less for drivers with LDWS compared to drivers without LDWS. Note: The severity of driving errors increased in later driving, indicating possible habituation to the LDWS.
Caveats/Comments: 120 lane departure events occurred without warning alarms for drivers with LDWS. It is unclear whether these missing LDW can be attributed to intentional behavior on the part of drives (e.g., braking, turn signals, etc.) to prevent annoying warnings.

Document: Wilson, B, H, Stearns, M. D., Koopmann, J., & Yang, C. Y. D. (2007). *Evaluation of a Road-Departure Crash Warning System.* (Report No. DOT HS 810 854). Washington, DC: National Highway Traffic Safety Administration.
Safety System: LDW/CSW system
Vehicle Type: Passenger Vehicles
Study Type: Field Test
General Approach: 78 drivers performed naturalistic driving for four weeks in vehicles equipped with LDW and CSW. In the first week, no warnings were presented.
Measures of Effectiveness: 1) LDW Availability. 2) Lane keeping. 3) Turn signal use. 4) Road departure conflicts. 5) Subjective responses.
Quality: High
Quality Note:
Applicability: Med
Applicability Note: Study not directly related to heavy vehicles.

Key Findings and Recommendations:
- *LDW Availability:*
  o Overall the LDW was available for 55% of miles driven.
- *Lane keeping: Lane Offset, Lane Offset Standard Deviation:*
  o Drivers drove an average of 0.79 inches closer to the center line with LDW.
  o LOSD improved from 0.22 meters to 0.21 meters.
  o No negative unintended consequences while using the RDCW.
- *Turn signal use:*
  o Turn signal use when changing lanes increased significantly from 61.5% to 69.0%
- *Road departure conflicts:*
  o The baseline conflict rate of 1.76 per 100 km decreased by 31%.
  o Daytime-departure-conflict rate of 1.97 per 100 km decreased by 40%.
  o At speeds greater than 55 mph, the baseline-departure-conflict rate of 2.64 per 100 km decreased by 44%.
- *Subjective responses:*
  o Drivers reported that they knew how to respond to LDW warnings.
  o Drivers reported that they were more aware of their lane position when using LDWS.

Caveats/Comments: None.

ELECTRONIC STABILITY CONTROL REVIEWS

Document:

Bahouth, G. (2005). Real world crash evaluation of Vehicle Stability Control (VSC) technology, *Association for the Advancement of Automotive Medicine 49th Annual Conference*, 19-34.

Safety System:

ESC

Vehicle Type:

Passenger Vehicles / Light Trucks

Study Type:

Crash Data Analysis

General Approach:

Police reported crash data from NHTSA's State Data System were used to determine the per-vehicle crash involvement rates for identical vehicle models with and without ESC. Models investigated consisted primarily of those that switched from ESC unavailable or as an optional feature to ESC as a standard vehicle option in consecutive model years (Toyotas exclusively).

Measures of Effectiveness:

1) Crash rate per registered vehicle.

Quality:

High

Quality Note:

Applicability:

Med

Applicability Note:

MOE approach is applicable, however the findings themselves cannot be generalized to heavy trucks, and they also likely only apply to higher-end passenger vehicles.

Key Findings and Recommendations:

Crash rate per vehicle registration:

Single Vehicle Crashes – ESC was associated with 53% fewer crashes overall.

- Multiple Vehicle Frontal Crashes – ESC was associated with 11% fewer crashes overall.

Note: Vehicle age was controlled for since non-ESC models were older and older vehicles (>3 yrs) are associated with slight higher crash rates. Also, rear-impact crash rates were used to control for vehicle exposure.

Caveats/Comments:

None.

Document:

Battelle. (2003). Final Report—Evaluation of the Freightliner Intelligent Vehicle Initiative Field Operational Test, Contract No. DTFJ61-96-C-00077, Task Order 7718.

Safety System:

ESC (Roll Advisory & Control)

Vehicle Type:

Heavy Truck

Study Type:

Field Study

General Approach:

- Fifteen experienced drivers drove six tractors equipped with RSC during on single-shift operation over a 13-month period. The baseline period lasted 5–7 months, after which time drivers received system training and the system became active (the system collected vehicle data during baseline).
- An instrumented tanker trailer (outfitted with outriggers) similar to the ones in the FOT was driven on a test track to identify system performance approaching roll-over conditions.

Measures of Effectiveness:

1) Speed entering a curve.
2) Probability of a rollover (rollover Ratio & Rollover Index).
3) Safety Benefits.
4) Cost Effectiveness (societal).
5) User Acceptance.

Quality:

High

Quality Note:

Applicability:

High

Applicability Note:

Key Findings and Recommendations:

Speed entering a curve: There was a small but statistically significant decrease in overall speed after a warning was presented (except on ramps), however, no conclusive evidence was found that drivers receiving a warning on a curve will drive the same curve more slowly in the future.

Probability of a rollover: The RSC did not activate during a risky maneuver during the FOT, primarily because drivers managed to avoid the conditions that would trigger the system.

The occurrence of incidents in which the Rollover Index was greater than 55% was lower during the test phase than the baseline phase (especially for higher index values), but there were too few incidents to evaluate this measure statistically.

Safety Benefits: Based on risk calculations incorporating speed data, it was estimated that rollover warnings could help prevent 20% of untripped rollover crashes caused by high speed in curves or turns. In particular, the system appeared to significantly reduce exposure to crash-causing situations, however, the estimated efficacy of the system in preventing crashes after those crash-causing situations occur was not significant.

Cost Effectiveness: The societal benefits in terms of safety, mobility, efficiency, productivity, and environmental improvements in comparison to fleet-wide implementation and operation costs were found to be highest with tanker trailers, marginal for tractor trailers, and cost ineffective for large trucks.

User Acceptance: Overall acceptance of the systems was good, and drivers felt that the messages were easy to read and understand in the time available. The system was not perceived as increasing workload or stress.

Test Track Data:

RSC can improve vehicle stability in several instances. In test runs, the RSC system prevented rollover states observed without the system under the same conditions (increasing speed into constant-radius turns).

The system was ineffective in preventing rollovers in curse driven at a constant speed but with a sudden tightening of the path.

Chances of a rollover are significantly lower at speeds below 25 km/h.

Caveats/Comments:

None.

Document: Ervin, R. D. (1998). Two Active Systems for Enhancing Dynamic Stability in Heavy Truck Operations. Ann Arbor: University of Michigan Transportation Research Institute.
Safety System: ECS (Roll Advisory & Control + RAMS [Rearward Amplification Suppression])
Vehicle Type: Heavy Trucks
Study Type: On-road study
General Approach: Drove three different test routes under various loading conditions.
Measures of Effectiveness: 1) Rollover Threshold. 2) Lateral Acceleration.
Quality: Med
Quality Note: This was more of a proof-of-concept than a systematic evaluation.
Applicability: High
Applicability Note:
Key Findings and Recommendations: *RSA:* The algorithms used to predict axle-liftoff were successful in estimating liftoff within 10 percent. No data are provided regarding driver performance or training benefits. *RAMS*: The system improved roll stability and tracking response of doubles combination in obstacle avoidance situations (40% reduction in reward amplification).
Caveats/Comments: This report does not evaluate the efficacy of the system but rather the efficacy of the prediction algorithms, which seems to be good.

Document:

Farmer, C. M. (2004). Effect of Electronic Stability Control on Automobile Crash Risk, *Traffic Injury Prevention* 5, 317-325

Safety System:

ESC

Vehicle Type:

Passenger Vehicles / Light Trucks

Study Type:

Crash Data Analysis

General Approach:

Police reported crash data from NHTSA's State Data System and from FARS were used to determine the per-vehicle crash involvement rates for identical vehicle models with and without ESC. Models investigated consisted primarily of those that switched from ESC unavailable or as an optional feature to ESC as a standard vehicle option in consecutive model years.

Measures of Effectiveness:

1) Crash rate per registered vehicle.

Quality:

High

Quality Note:

Applicability:

Med

Applicability Note:

MOE approach is applicable, however the findings themselves cannot be generalized to heavy trucks, and they also likely only apply to higher-end passenger vehicles.

Key Findings and Recommendations:

- *Crash rate per vehicle registration:*
  - Single Vehicle Crashes—ESC was associated with:
    - 41% fewer crashes overall.
    - 41% fewer injury crashes.
    - 56% fewer fatal crashes.
  - Multiple Vehicle Crashes—ESC was associated with:
    - 3% fewer crashes overall (not significant).
    - 5% fewer injury crashes (not significant).
    - 17% fewer fatal crashes (not significant).

Note: Vehicle age was controlled for since non-ESC models were older and older vehicles (>3 yrs) are associated with slight higher crash rates.

Caveats/Comments:

None.

Document: Farmer, C. M. (2006). Effects of Electronic Stability Control: An Update, *Traffic Injury Prevention*, 7, 319-324
Safety System: ESC
Vehicle Type: Passenger Vehicles / Light Trucks
Study Type: Crash Data Analysis
General Approach: Police reported crash data from NHTSA's State Data System and from FARS were used to determine the per-vehicle crash involvement rates for identical vehicle models with and without ESC. Models investigated consisted primarily of those that switched from ESC unavailable or as an optional feature to ESC as a standard vehicle option in consecutive model years.
Measures of Effectiveness: 1) Crash rate per registered vehicle.
Quality: High
Quality Note:
Applicability: Med
Applicability Note: MOE approach is applicable, however the findings themselves cannot be generalized to heavy trucks, and they also likely only apply to higher-end passenger vehicles.
Key Findings and Recommendations: - *Crash rate per vehicle registration for Passenger Vehicles:* o ESC was associated with: ▪ 33% fewer crashes overall. ▪ 33% fewer injury crashes. ▪ 53% fewer fatal crashes. ▪ - *Crash rate per vehicle registration for SUVs:* o ESC was associated with: ▪ 49% fewer crashes overall. ▪ 66% fewer injury crashes. ▪ 59% fewer fatal crashes. Most results for multiple vehicle crashes are not significant. Note: Vehicle age was controlled for since non-ESC models were older and older vehicles (>3 yrs) are associated with slight higher crash rates.
Caveats/Comments: None.

Document: Freightliner (2007). Electronically Controlled Braking Systems (ECBS) intelligent vehicle initiative field operational test. Combined templates 2 and 3: Mixed and optimized tractor-trailer. Washington, DC: Federal Highway Administration.
Safety System: Electronically Controlled Braking Systems (with RSC-Roll Stability Control & RSS-Roll Stability Support)
Vehicle Type: Heavy Truck
Study Type: Field Study
General Approach: 48 tractors and 100 trailers were outfitted with various combinations of standard braking systems and ECBS systems, in addition with a subset receiving RSC, RSS, or ESC systems. Vehicles were fielded for 12 months in a normal operating environment, first without the technology and later with the technology (variable phase durations).
Measures of Effectiveness: 1) Lateral Acceleration. 2) Driver Survey Responses.
Quality: Med
Quality Note: High quality study, however, the key MOE data was too inaccurate to use to evaluate vehicle stability.
Applicability: High
Applicability Note:
Key Findings and Recommendations: - *Lateral Acceleration*: Accuracy of this measure was too low to provide useful analysis of the safety benefits of these systems on vehicle stability. - *Survey Responses*: All drivers surveyed felt the ESC assisted them in maintaining vehicle control. The responses were split 50/50 regarding whether the drivers drove an ECBS tractor with ESC differently.
Caveats/Comments: This report provides little in the way of detailed findings. Conclusions of regarding the quality of lateral acceleration data were taken from the NHTSA independent evaluation of this FOT: http://www.nhtsa.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811078.pdf

Document: Green, P. E., & Woodrooffe, J. (2006). The Effectiveness of Electronic Stability Control on Motor Vehicle Crash Prevention (UMTRI-2006-12). Ann Arbor: University of Michigan Transportation Research.
Safety System: ESC
Vehicle Type: Passenger Vehicles / Light Trucks
Study Type: Crash Data Analysis
General Approach: Police reported crash data from FARS and GES were used in a Case-Control (induced exposure) analysis design to estimate the safety benefits of ESC. Analysis of single vehicle crashes compared vehicle models that switched from ESC unavailable or as an optional feature to ESC as a standard vehicle option in consecutive model years. An alternative analytical approach in which the control group consisted of crashes that would not have benefited from ESC (rear-end crashes) was also employed.
Measures of Effectiveness: 1) Crash rate reduction (%).
Quality: High
Quality Note:
Applicability: Med
Applicability Note: MOE approach is applicable, however the findings themselves cannot be generalized to heavy trucks, and they also likely only apply to higher-end passenger vehicles.
Key Findings and Recommendations: *Odds of fatal crash:* Single Vehicle Crashes—ESC was associated with: ▪ 30.5% fewer crashes in passenger cars. ▪ 49.5% fewer crashes in SUVs. Rollover Crashes – ESC was associated with: ▪ 39.7% fewer crashes in passenger cars. ▪ 72.9% fewer crashes in SUVs. *Odds of less severe crash (using rear-end crashes as control group):* Single Vehicle Crashes – ESC was associated with: ▪ 54.5% fewer crashes in passenger cars. ▪ 70.3% fewer crashes in SUVs. This approach also indicated that there were no differences based on gender, but middle-aged and older drivers benefited more from ESC. There was also a greater benefit of ESC on roads there were “not dry” for both types of vehicles. Note: Vehicles 3 model years or younger were analyzed separately, and showed a greater crash risk reduction for ESC, which suggests that vehicle age is not a relevant factor.
Caveats/Comments: None.

Document: Houser, A., Murray, D., & Dick, V (2007). *Onboard safety technology survey synthesis final report*. Washington, DC: Federal Motor Carrier Safety Administration.
Safety System: LDWS, ESC
Vehicle Type: Heavy Truck
Study Type: Literature Synthesis
General Approach: A synthesis of existing survey research was conducted to provide a broader understanding of the relationships and factors involved in the use, selection, and impact of onboard safety technologies. Information from 19 surveys, interviews, and focus group was covered in this synthesis.
Measures of Effectiveness: 1) **User Acceptance.**
Quality: High
Quality Note:
Applicability: Med
Applicability Note: Provides general information, however applicability is difficult to assess without technology descriptions from original sources.
Key Findings and Recommendations: Biggest safety challenges identified were Road-departure collisions, Lane-change/merge collisions, & Rear-end collisions. Crashes most often identified as preventable included Rollover, Run-off-road, and Rear-end crashes. Implementation of key technologies of interest was less than 10%. *Driver Acceptance:* Greater driver acceptance and easier driver use were identified as desirable benefits of future systems. LDWS: 80% of drivers activate the system when this option is available, and 75% feel that the test system provides valid warnings most of the time. System is effective in promoting alertness & satisfaction ratings are positive. SCS (same as Battelle 2003): Feedback was generally perceived as useful and the system was operating in a safe manner. Overall acceptance of the systems was good, and drivers felt that the messages were easy to read and understand in the time available. The system was not perceived as increasing workload or stress.
Caveats/Comments: None.

Document: Houser, A., Pape, D., & McMillan (2006). A simulation approach to estimate the efficacy of Meritor WABCO's Improved Roll Stability Control. Washington DC:FMCSA
Safety System: ESC (Roll Advisory & Control)
Vehicle Type: Heavy Truck
Study Type: Computer Simulation
General Approach: A computer simulation was developed to model the safety benefits of incorporating service-brake activation into RSC. The model is based on VDANL and uses performance data described in Battelle (2003) as input.
Measures of Effectiveness: 1) Safety Benefits.
Quality: High
Quality Note:
Applicability: High
Applicability Note:
Key Findings and Recommendations: *Safety Benefits:* The system was estimated to prevent about 53 percent of rollovers attributable to excessive speed in curves. Combining a RSC with driver advisor was estimated to 69 percent of those crashes.
Caveats/Comments: None.

Document: Houser, A., Murray, D., & Dick, V (2007). Onboard safety technology survey synthesis final report. Washington DC: FMCSA
Safety System: LDWS, ESC
Vehicle Type: Heavy Truck
Study Type: Literature Synthesis
General Approach: A synthesis of existing survey research was conducted to provide a broader understanding of the relationships and factors involved in the use, selection, and impact of onboard safety technologies. Information from 19 surveys, interviews, and focus group was covered in this synthesis.
Measures of Effectiveness: 1) User Acceptance.
Quality: High
Quality Note:
Applicability: Med
Applicability Note: Provides general information, however applicability is difficult to assess without technology descriptions from original sources.
Key Findings and Recommendations: Biggest safety challenges identified were Road-departure collisions, Lane-change/merge collisions, & Rear-end collisions. Crashes most often identified as preventable included Rollover, Run-off-road, and Rear-end crashes. Implementation of key technologies of interest was less than 10%. *Driver Acceptance:* Greater driver acceptance and easier driver use were identified as desirable benefits of future systems. LDWS: 80% of drivers activate the system when this option is available, and 75% feel that the test system provides valid warnings most of the time. System is effective in promoting alertness & satisfaction ratings are positive. SCS (same as Battelle 2003): Feedback was generally perceived as useful and the system was operating in a safe manner. Overall acceptance of the systems was good, and drivers felt that the messages were easy to read and understand in the time available. The system was not perceived as increasing workload or stress.
Caveats/Comments: None.

Document:

Murray, D., Shackelford, S., & Houser, A. (2009b). *Analysis of benefits and costs of roll stability control systems for the trucking industry* (FMCSA-RRT-09-020). Washington, DC: Federal Motor Carrier Safety Administration.

Safety System:

ESC (Roll Advisory & Control)

Vehicle Type:

Heavy Truck

Study Type:

Analytical Study / Crash Data Analysis

General Approach:

Rollover-related crash costs for combination trucks were compared against purchase, installation, and operating costs, to evaluate relative costs and benefits associated with RSC for the trucking industry. Costs calculated for Property-Damage-Only, Injury, and Fatal crashes using GES data.

Measures of Effectiveness:

1) Cost Effectiveness for Motor Carriers.

Quality:

High

Quality Note:

Applicability:

Med-High

Applicability Note:

Useful information about an indirect MOE, however, performance/safety data are taken from other studies.

Key Findings and Recommendations:

System efficacy rates were taken from a Computer simulation and a maximum of 53% and minimum of 37% crash prevention efficacy were assumed for the analysis.

Cost Effectiveness

Average direct "out-of-pocket" costs of rollover crashes for motor carriers that have deductibles at or above crash costs by type:

- PDO: $197K.
- Injury: $462K.
- Fatal: $1,143K.

Regardless of VMTs, medium-sized to large carriers with an average likelihood of rollover crashes will achieve positive returns.

Range of the positive return was $1.66 to $9.36 for each dollar spent, depending on cost assumptions.

Small carriers (with costs primarily covered by insurance) can achieve positive returns if one or more crashes are prevented.

Caveats/Comments:

None.

Document: Stevens, S. S., Chin, S. M., Hake, K.A., Hwang, H. L., Rollow, J. P., and Truett, L. F. (2001). *Truck Roll Stability Data Collection and Analysis* (ORNL/TM-2001/116): Oak Ridge, TN: Oak Ridge National Laboratory.
Safety System: ESC
Vehicle Type: Heavy Trucks
Study Type: Field Study
General Approach: Used instrumented heavy trucks to collect vehicle performance variables during curve navigation. Data collection included GPS data that provided information about the curve geometry.
Measures of Effectiveness: 1) Lateral Acceleration. 2) Estimated Acceleration based on GPS data.
Quality: Med
Quality Note: Minimal relevant methodological information is provided, and equipment issues limited data collection, particularly trailer data.
Applicability: Med-Low
Applicability Note: No safety system was implemented, and variables collected provide only basic insight regarding MOEs.
Key Findings and Recommendations: Most data reported are anecdotal data from single trip segments. *Lateral Acceleration:* Report provides a few geo-spatial maps showing the magnitude of lateral acceleration values at different points along a curve. There was some positive bias in the recorded data due to instrument drift. *Estimated Lateral Acceleration:* These estimates were systematically higher than the observed values on most curves. This arose from the fact that superelevation was not included in the estimated value.
Caveats/Comments: This report is a technology summary and does not provide any technical descriptions of the methods and results.

Document: Winkler, C., Sullivan, J., Bogard, S., Goodsell, R., & Hagan, M. (2002). Field Operational Test of the Freightliner/Meritor WABCO Roll Stability Advisor and Control at Praxair (pp. 360): Federal Highway Administration.
Safety System: ESC (Roll Advisory & Control & unusual brake event detection)
Vehicle Type: Heavy Truck
Study Type: Field Test
General Approach: 14 experienced CVO drivers participated in a field study that was used to measure the effects of an ESC on driver behavior in curve driving, and the corresponding crash risk. Participants drove without (baseline: 6 months) system and with the system (6 month), and concurrent factors that could affect driver performance (weather, lighting, turn severity, etc.) were also recorded.
Measures of Effectiveness: 1) Lateral Acceleration at driver's position (which reflects the drivers experience). 2) Roll-over Ratio (actual risk of roll-over, taking account cross-slope & super-elevation). 3) Subjective ratings from drivers of system performance.
Quality: Med-High
Quality Note: Small sample size and limited ability to attribute significant effects to ESC rather than external factors.
Applicability: High
Applicability Note:
Key Findings and Recommendations: *Lateral Acceleration*: Turning performance was more conservative with loaded vehicles. *Roll-over Risk*: Turning performance was less conservative with loaded vehicles. *Both*: Turning performance was less conservative at lower speeds, and more conservative in the dark, in bad weather, and for left turns. *Warning Messages*: 93% of warnings issued with empty vehicles, which impacted driver perception of usefulness. *System Effectiveness*: Main effect of ESC was not significant, but certain situations did show small but significant effects, including severe turns in good weather and severe turns to the right. Behavior in severe turns was significantly more conservative following warnings (especially within the first 250 km of driving).
Caveats/Comments: None.

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APPENDIX D: CARRIER DEMOGRAPHIC AND INFORMATION SHEET

CARRIER DEMOGRAPHIC AND INFORMATION SHEET

I want to thank you for your participation in this research project to evaluate the effectiveness of three different onboard safety systems using data collected directly from motor carriers. To remind you, we are evaluating:

- Lane departure warning systems.
- Electronic stability control systems.
- Forward collision warning systems.

I have a few questions regarding information about your fleet and the use of lane departure warning systems, electronic stability control systems, and forward collision warning systems. The questionnaire will take approximately 10-15 minutes to complete, do you have a few minutes to answer these questions? There are no right or wrong answers, please answer all the questions to the best of your ability. Please note the information you provide will be anonymous.

Carrier ID#: _____________

DOT#: _______________

Forward collision warning: If yes, then complete Section 2a

a. Make: _______________________ Model: ______________________

Electronic stability control/roll stability control: If yes, then complete Section 2b

___ Rollover Stability Control (active systems that automatically intervene if a high rollover risk is detected because of excessive speed in a curve).

a. Make: _______________________ Model: ______________________

Lane departure warning: If yes, then complete Section 2c

a. Make: _______________________ Model: ______________________

SafeStat Score: _______

Accident SEA: _____

Driver SEA: _______

Vehicle SEA: ______

Safety Management SEA: ______

Section 1: Carrier Information

1. Description of carrier (check all that apply)
    a. For-hire: truckload
    b. For-hire: less-than-truckload
    c. For-hire: regional
    d. For-hire: tanker
    e. Private: truckload
    f. Private: less-than-truckload
    g. Private: regional
    h. Private: tanker
    i. Owner-operator
    j. Other: ___________
2. Number of power units
    a. 1–10 power units
    b. 11–50 power units
    c. 51–100 power units
    d. 101–500 power units
    e. 501–1,000 power units
    f. 1,001 or more power units
3. Average length of haul:
    a. 1–50 miles
    b. 51–100 miles
    c. 101–200 miles
    d. 201–499 miles
    e. 500 or more miles
    f. Pick up & Delivery
4. Primary commodities (check all that apply):
    a. General freight truckload
    b. General freight less-than-truckload
    c. Building materials
    d. Hazardous chemicals
    e. Processed foods
    f. Heavy machinery
    g. Refined petroleum products
    h. Automotive parts or vehicles
    i. Forest products
    j. Farm fresh products
    k. Household goods
    l. Retail store—grocery delivery
    m. Raw petroleum products

n. Bulk—dump truck
o. Parcels
p. Mine ores
q. Other: ______________________________________

5. Number of regular, full-time employees:
    a. 1–20 regular, full-time employees
    b. 21–100 regular, full-time employees
    c. 101–500 regular, full-time employees
    d. 501–1,000 regular, full-time employees
    e. 1,001–5,000 regular, full-time employees
    f. 5,000 or more regular, full-time employees
6. How is your company insured?
    a. Self-insured
    b. Private insurance
    c. Other (please indicate)________________________
7. Average driving experience of drivers (in years): ___________
8. Other onboard safety systems, such as Xata, DriveCam, etc. you currently employ (list all that apply). If you do not have any other onboard safety systems, please skip to question #9.
    a. Make: ______________________ Model: ______________________
    b. Make: ______________________ Model: ______________________
    c. Make: ______________________ Model: ______________________
    d. Make: ______________________ Model: ______________________
9. Onboard safety systems, such as Xata, DriverCam, etc. (including the systems we are currently evaluating) that you had in the past but no longer use (for example, pilot tested but decided not to use). If you have not had any onboard safety systems in the past, please skip to question #11.
    a. Make: ______________________ Model: ______________________
    b. Make: ______________________ Model: ______________________
    c. Make: ______________________ Model: ______________________
    d. Make: ______________________ Model: ______________________
10. If you had onboard safety systems in the past that are no longer used (for example, pilot tested but decided not to use), why did you decided to stop using it?
    ____
11. Speed limiters: Y/N
    a. Set speed: ____________
12. Cell phone policy: Y/N
    a. Specific policy:____
13. Safety management techniques (check all that apply):
    a. Driver finishing program
    b. Yearly training/re-training (general)
    c. How’s my driving safety placards
    d. Safety incentives
    e. Fuel bonus
    f. Defensive driving training (e.g., smith system, etc.)
    g. Fatigue countermeasure training
    h. Ride alongs
    i. Spot checks
    j. Health and wellness program
    k. Other:____

Section 2: Use of Onboard Safety Systems

Now I'm going to ask you a few questions regarding your (list specific OBSSs). Most of these questions concern the costs associated with installation, maintenance, and training. These are necessary to determine the cost-benefit (or return-on-investment) for each OBSS. Again, the information you provide will be anonymous. Please answer all these questions to the best of you ability. If you do not know the answer, we will contact the vendor for more information.

Forward Collision Warning

Is adaptive cruise control standard or optional with your system?

___ Standard

___ Optional

Please indicate a price range for the forward collision warning systems you provide.

$_________ to $_________

With adaptive cruise control: $_________ to $__________

Without adaptive cruise control: $ _________ to $_________

Do these costs mentioned above include the (Check all that apply)

___ Equipment

___ Training (skip 4 and 5)

___ Installation (skip 6)

___ Maintenance (skip 7 and 8)

What is the suggested number of hours needed to train a driver to use your system?

____

What is the average cost of training?

$__________

What is the average per-unit *installation* cost for the technology?

$__________

What are the average annual per-unit *ongoing* (i.e., inspection, maintenance, etc.) costs for the technology?

$__________

What do these ongoing costs include (check all that apply)?

___ Maintenance

___ Inspection

___ Other: ____________________

What is the service life of this technology?

____

Did your company receive a any discount based on number of systems purchased? Y/N

When paying for the equipment did your company:

___Pay up front

___Finance the purchase over _____ years

What is the average interest rate that your company paid for a loan period of three years when buying this type of technology? _______

What is the average vehicle miles traveled per truck that is equipped with this technology?

____

On average, how many drivers use a truck equipped with this technology (e.g., 1 driver per truck, 2 drivers per truck, etc.)?

______

Rollover Stability System

Please indicate a price range for the Rollover Stability System/Electronic Stability Control System.

Rollover Stability Control: $__________ to $__________

Electronic Stability Control: $__________ to $__________

These costs mentioned above include the (Check all that apply)

___ Equipment

___ Training (skip 3 and 4)

___ Installation (skip 5)

___ Maintenance (skip 6 and 7)

What is the suggested number of hours needed to train a driver to use your system?

____

What is the average cost of training?

$__________

What is the average per-unit *installation* cost for the technology?

$__________

What are the average annual per-unit *ongoing* (e.g., maintenance, inspection, etc.) costs for the technology?

$__________

What do these ongoing costs include (check all that apply)?

___ Maintenance

___ Inspection

___ Other: ____________________

What is the service life of this technology?

____

Did your company receive any discount based on number of systems purchased? Y/N

When paying for the equipment did your company:

___ Pay up front

___ Finance the purchase over _____ years

What is the average interest rate your company paid for a loan period of three years when buying this type of technology? _______

What is the average vehicle miles traveled per truck that is equipped with this technology?

____

On average, how many drivers use a truck equipped with this technology (e.g., 1 driver per truck, 2 drivers per truck, etc.)?

______

Lane Departure Systems

Please indicate a price range for the Lane Departure Warning system you provide.

$_________ to $_________

These costs mentioned above include the (Check all that apply)

___ Equipment

___ Training (skip 3 and 4)

___ Installation (skip 5)

___ Maintenance (skip 6 and 7)

What is the suggested number of hours needed to train a driver to use your system?

____

What is the average cost of training?

$__________

What is the average per-unit *installation* cost for the technology?

$__________

What are the average annual per-unit *ongoing* (i.e., maintenance, inspection, etc.) costs for the technology?

$__________

What do these ongoing costs include (check all that apply)?

___ Maintenance

___ Inspection

___ Other: ____________________

What is the service life of this technology?

____

Did your company receive any discount based on number of systems purchased? Y/N

When paying for the equipment did your company:

___ Pay up front

___ Finance the purchase over _____ years

What is the average interest rate your company paid for a loan period of three years when buying this type of technology? _______

What is the average vehicle miles traveled per truck that is equipped with this technology?

____

On average, how many drivers use a truck equipped with this technology (e.g., 1 driver per truck, 2 drivers per truck, etc.)?

______

Thank you again for taking the time to complete this questionnaire! Please feel free to contact me if you have any questions regarding this project and or the information you provided. You can contact me at: mcamden@vtti.vt.edu or (540) 231-1503.

APPENDIX E: SOURCES FOR SUMMARY OF CURRENT AND EMERGING OBSS DEVICES

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APPENDIX F: FOCUS GROUP PROCEDURES/QUESTIONS

I. GREETINGS AND INFORMED CONSENT (10 MINUTES)

Participants will be greeted and escorted to the conference room.

An investigator will check each participants CDL to verify that it is valid/current.

Participants will be given the Informed Consent Form and asked to read the form and voice any concerns or questions that they have to an investigator.

If subjects wish to participate, they will be asked to sign the Informed Consent Form. One form will be collected by the experimenter and a copy will be given to the participant to keep for their own records.

Those who choose not to participate may leave.

Participants will be reminded that they may refuse to answer any questions and may leave at anytime.

II. FACILITATOR INTRODUCTION AND GROUND RULES (5 MINUTES)

Hello, my name is ____________. I'm a researcher at the Virginia Tech Transportation Institute. We want to thank you for taking the time (today/this morning/this evening) to come and share your thoughts and opinions with us.

PURPOSE OF THE MEETING

Purpose of this meeting is to discuss issues related to onboard safety systems.

We are going to ask you a series of questions and need you to respond as openly and honestly as possible. There are no right or wrong answers—we just want your opinions.

CONFIDENTIALITY

The discussion tonight is strictly for research purposes, we are not selling anything and we will not connect anything you say with your name.

There is a tape recorder in the room. Please speak loudly and clearly so that we get a good recording of your comments.

There will be a transcript of this discussion, but it will not match comments with names.

Recordings will be stored in a secure location and erased after they are transcribed.

If you feel uncomfortable, you can refuse to answer a question or you may leave.

Did everyone fill out one of these consent forms? Do you have any questions about it?

LOGISTICS

This meeting will run until ______ (time), we are very appreciative of the time that you are spending and will honor it by not running over.

Bathrooms are located XXXXXXXXXXXX (indicate locations). If you would like something to eat or drink please help yourself now before we get started. We will also have a break later.

Please turn off any phones/beepers unless you need them on for emergency reasons. This will help us to avoid distractions and finish on time.

GROUND RULES

Please let me know if you are uncomfortable with any of these rules. If you are ok with these rules, then let's agree to abide by them for the remainder of the meeting.

Avoid full names, nicknames, or other identifying information (use of first name is acceptable)

Listen to each other

<u>Everyone</u> participate fully

No side conversations

Spelling does not count

Don't criticize others

Finish on time

Return from break in a timely manner

III. FACILITATOR QUESTIONS AND DISCUSSION RULES (40 TO 60 MINUTES)

Note. These are primary questions (probes). Additional, in-depth, follow up questions may be used and will depend on the responses given to these primary questions. These follow up questions will be directly related to the general line of questions presented herein.

Introduction/Onboard Safety Systems

- How is the OBSS installed (e.g., each new truck, new drivers, risky drivers, other) (safety managers only)?
- Describe how you use/interact with the onboard safety system in your daily driving.
  - How has the onboard safety system changed your driving?
  - Can you see a difference between how you drove without the system and how you drive with the system?
  - How aware are you of the system?

- Overall, do you think the OBSS is easy to use?
  - What aspects are easy?
  - What aspects are difficult?
- What are the benefits of the onboard safety system?
  - Have participants list their top 3 perceived benefits on post-it notes. Numbered from “1” to “3” with “1” being the #1 benefit and so on.
  - Collect post-its and place them in topic areas. Ask if there were any other benefits that come to mind.
- What are the disadvantages of the onboard safety system?
  - Have participants list their top 3 perceived disadvantages on post-it notes. Numbered from “1” to “3” with “1” being the #1 disadvantage and so on.
  - Collect post-its and place them in topic areas. Ask if there were any other disadvantages that come to mind.
- What improvement(s) would you make to the onboard safety system?
  - How would that change/address the disadvantage noted?
  - How would that change/improve the system (i.e., make the system easier to use)?
  - Would the changes improve the accuracy and reliability of the onboard safety system?
  - Would it improve your or others acceptance/willingness to use OBSS?
  - Did you receive any training in using the onboard safety system? Please share what your training process entailed.
  - How much training did you receive (time wise)?
  - What was the training process?
  - Do you feel the training prepared you to use the OBSS effectively?
    - Did you receive too much training/Not enough training?
    - Did the training provide you with an understanding of how the OBSS system works and the reasons for implementing the use of the system?
- Can you provide an example of a situation where you saw the benefits of the OBSS first-hand?
  - Have you seen any instances while you were driving where it prevented a crash?
  - Has having the OBSS minimized the severity of a crash?
  - Do you think it has the potential to prevent crashes or minimize the severity of a crash
- Would you recommend the onboard safety system to other drivers/safety managers?
  - What aspects of the OBSS would you specifically recommend?
  - Are there aspects that you wouldn’t recommend?
- Does the cost of the onboard safety system justify its use (safety managers only)?

  - What aspects of the OBSS would you specifically recommend?
  - Are there aspects that you wouldn't recommend?
- Would you remove the onboard safety system if you were given the opportunity?
  - Have you removed the system?
  - Do you perceive resistance from other drivers to the implementation of OBSS within their trucks?
  - Do you think drivers would circumvent the system (e.g., turning off the sound alerts, covering cameras, etc.)?
- Please give your overall opinion of the onboard safety system?
- Are there any other issues related to the OBSS that you think we should have discussed today that we haven't?

APPENDIX G: DRIVER AND SAFETY MANAGER DEMOGRAPHIC QUESTIONNAIRES

Option 1 (Drivers)

Driver#___________ Date:_____________

Instructions: Thank you for taking the time to fill in this questionnaire! It should take you about 5–10 minutes to complete but you will be given as much time as needed. Please answer each of the following items as honestly as possible.

THERE ARE NO RIGHT OR WRONG ANSWERS.

Select your answers quickly and do not spend too much time thinking about your answers. If you change an answer, erase the first one well. The information you provide will be kept confidential and will not be shared with any of your managers or other drivers.

What is your age (check one)?

Under 24

25-34

35-44

45-54

55-64

65-74

75 and older

Please select your gender (check one): _ Male _ Female

Marital Status (please check one)

_ Single

_ Married

_ Divorced

_ Widow

_ Living with significant other, but not married

Please estimate the following:

Weight: ______ (lbs)

Height: ______ (ft, in)

Neck circumference: ________ (in)

How are you compensated at your job (please check one)?

_ By the mile

_ By the load

_ By the hour

_ Other: ___________

Please list your safety awards (million miler, etc.)?

____

What's your highest level of education (please check one):

_ Did not complete High School
_ High School (Grade 12 or GED certificate)
_ Technical, trade, or vocational school AFTER high school
_ Some College
_ Associate Degree (2-year degree)
_ College Graduate (B.S., B.A. or other 4-year degree)
_ Master's degree

_ Professional or terminal degree

_ Doctorate degree

Which of the following groups is most representative of your background (check one)?

_ African/American

_ Caucasian/American

_ Hispanic/American

_ Middle Eastern

_ Asian/American

_ Pacific Islander

_ Native American

_ Other (please list)______________

How long have you been driving commercial vehicles? _____years _____months

How long have you been working for this company? _____years _____months

How long have you driven a truck equipped with one of the following onboard safety systems?

Electronic stability control _____years _____months

Forward collision warning _____years _____months

Lane departure warning _____years _____months

Are you a member of a professional or labor organization (check one)?

_ No

_ Yes. Which one? ___________

Do you currently hold a CDL? _ Yes _ No

How long have you held your CDL? _____years _____months

If you have your CDL, please indicate the type of Commercial Driver's License (CDL) and Endorsements that you hold: (select all that apply)

CDL Type

- Class A
- Class B
- Class C
- Other (please describe): ______________
- None

Endorsements

- (P) – Passengers
- (T) – Doubles/Triples Trailers
- (N) – Tank Vehicle
- (H) – Hazardous Materials (HazMat)
- (X) – Combination of Tank Vehicle and HazMat
- (S) or (SB) – School Bus
- None

What is the vehicle configuration that you primarily operate? (Check one)

5-axle Flatbed

5-axle Dry Van

5-axle Tanker

Straight Truck

Long-Combination Vehicles (Doubles, Triples, etc.)

Other (please describe): ______

What percentage of the time do you move freight based on the following trip lengths (total percent should equal 100):

Operation Percentage

Local (less than 100 miles) ___________________

Short Haul (100 to 500 miles) ___________________

Long Haul (more than 500 miles) ___________________

Total ___________________

Questions 17-19 refer to *both* commercial (professional) and personal driving experience. Please enter a value for each question, even if it is 0 (zero).

For each of the vehicle types, how many moving violations (speeding, illegal passing, etc.) have you had in the:

Commercial Vehicle:

Last 12 months:______________ Last 36 months: ________________

Personal Vehicle:

Last 12 months:______________ Last 36 months: ________________

For each of the vehicle types, how many vehicular crashes have you been involved in during the:

Commercial Vehicle:
Last 12 months:______________ Last 36 months: ________________

Personal Vehicle:
Last 12 months:______________ Last 36 months: ________________

For each of the vehicle types, how many of these crashes were considered "your fault" during the:

Commercial Vehicle:

Last 12 months:______________ Last 36 months: ________________

Personal Vehicle:

Last 12 months:______________ Last 36 months: ________________

Thank you for your time!

Option 2 (Safety Managers)

Safety Manager#________ Date:______________

Instructions: Thank you for taking the time to fill in this questionnaire! It should take you about 5–10 minutes to complete but you will be given as much time as needed. Please answer each of the following items as honestly as possible.

THERE ARE NO RIGHT OR WRONG ANSWERS.

Select your answers quickly and do not spend too much time thinking about your answers. If you change an answer, erase the first one well. The information you provide will be kept confidential and will not be shared with any of your managers or other safety managers.

What is your age (check one)?

Under 24

25–34

35–44

45–54

55–64

65–74

75 and older

Please select your gender (check one): _ Male _ Female

What's your highest level of education (check one):

_ Did not complete High School
_ High School (Grade 12 or GED certificate
_ Technical, trade, or vocational school AFTER high school
_ Some College
_ Associate Degree (2-year degree)
_ College Graduate (B.S., B.A. or other 4-year degree)
_ Master's degree

_ Professional or terminal degree

_ Doctorate degree

Which of the following groups is most representative of your background? (Check one)

_ African/American _ Asian/American

_ Caucasian/American _ Pacific Islander

_ Hispanic/American _ Native American

_ Middle Eastern _ Other (please list)__________________

Do you currently hold a CDL? _ Yes _ No

How long have you held your CDL? _____years _____months

If you have your CDL please indicate the type of Commercial Driver's License (CDL) and Endorsements that you hold (check all that apply):

CDL Type

- Class A
- Class B
- Class C
- Other (please describe): ______________
- None

Endorsements

- (P) – Passengers
- (T) – Doubles/Triples Trailers
- (N) – Tank Vehicle
- (H) – Hazardous Materials (HazMat)
- (X) – Combination of Tank Vehicle and HazMat
- (S) or (SB) – School Bus
- None

How long have you been working for this company? _____years _____months

Please identify the major activities for which you are responsible (check all that apply):

Commercial Truck Driving

Loss Prevention/Risk Management

Human Resource Operations

Technology/Asset Investment

Terminal/Dock Operations

Safety Management/Compliance

Accounting/Payroll

Senior Executive

Fleet Operations

Dispatch/Routing

Maintenance

Customer Service

Other (please specify): ________________

How long have you managed drivers in trucks equipped with one of the following onboard safety systems?

Electronic stability control _____years _____months

Forward collision warning _____years _____months

Lane departure warning _____years _____months

Are you a member of a professional or labor organization (check one)?

_ No

_ Yes. Which one? ___________

How many Class-A CDL drivers does your company employ or contract? ___________

How many power units are in your company's fleet? ___________

How many trailers/tank trailers are in your company's fleet? ___________

Which sector of the trucking industry do you operate in most of the time (check one)?

For-hire

Private Fleet

Other (please specify): __________

What is your company's primary type of business (check all that apply):

Truckload

Less-Than-Truckload

Bulk/Tankers

Hazmat

Specialized

Other (please specify): __________

Thank you for your time!

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APPENDIX H: SPECIFIC BCA VALUES

Table 64. Carrier and Societal BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**BCR**	**NPV**	**Payback Period (0%)**	**BCR**	**NPV**	**BCR**	**NPV**	**Payback Period (0%)**
Low Cost Estimate (LCE) 3%	60,000	0.42	-$650	144	0.36	-$751	0.35	-$1,019	163
LCE 3%	80,000	0.56	-$510	108	0.48	-$612	0.46	-$837	122
LCE 3%	100,000	0.70	-$371	86	0.60	-$472	0.58	-$655	98
LCE 3%	120,000	0.84	-$232	72	0.72	-$333	0.70	-$474	82
LCE 3%	140,000	0.98	-$92	62	0.83	-$194	0.81	-$292	70
LCE 3%	160,000	1.11	$47	54	0.95	-$54	0.93	-$110	61
LCE 3%	180,000	1.25	$187	48	1.07	$85	1.05	$72	54
LCE 7%	60,000	0.36	-$663	144	0.35	-706	0.33	-$1,010	163
LCE 7%	80,000	0.48	-$538	108	0.46	-582	0.43	-$847	122
LCE 7%	100,000	0.60	-$413	86	0.58	-457	0.54	-$685	98
LCE 7%	120,000	0.72	-$289	72	0.69	-332	0.65	-$522	82
LCE 7%	140,000	0.84	-$164	62	0.81	-207	0.76	-$359	70
LCE 7%	160,000	0.96	-$39	54	0.92	-82	0.87	-$197	61
LCE 7%	180,000	1.08	$86	48	1.04	43	0.98	-$34	54
Average Cost Estimate (ACE) 3%	60,000	0.30	-$970	186	0.27	-$1,105	0.27	-$1,504	213
ACE 3%	80,000	0.40	-$831	140	0.37	-$966	0.35	-$1,322	160
ACE 3%	100,000	0.50	-$691	112	0.46	-$827	0.44	-$1,141	128
ACE 3%	120,000	0.60	-$552	93	0.55	-$687	0.53	-$959	107
ACE 3%	140,000	0.70	-$412	80	0.64	-$548	0.62	-$777	91
ACE 3%	160,000	0.80	-$273	70	0.73	-$408	0.71	-$596	80
ACE 3%	180,000	0.90	-$134	62	0.82	-$269	0.80	-$414	71
ACE 7%	60,000	0.28	-$977	186	0.27	-$1,105	0.25	-$1,477	213
ACE 7%	80,000	0.37	-$852	140	0.35	-$966	0.33	-$1,315	160
ACE 7%	100,000	0.46	-$727	112	0.44	-$827	0.41	-$1,152	128
ACE 7%	120,000	0.55	-$602	93	0.53	-$687	0.50	-$989	107
ACE 7%	140,000	0.65	-$478	80	0.62	-$548	0.58	-$827	91
ACE 7%	160,000	0.74	-$353	70	0.71	-$408	0.66	-$664	80
ACE 7%	180,000	0.83	-$228	62	0.80	-$269	0.74	-$501	71
High Cost Estimate (HCE) 3%	60,000	0.24	-$1,290	229	0.22	-$1,459	0.22	-$1,990	264
HCE 3%	80,000	0.33	-$1,151	172	0.30	-$1,320	0.29	-$1,808	198
HCE 3%	100,000	0.41	-$1,012	137	0.37	-$1,180	0.36	-$1,626	158
HCE 3%	120,000	0.49	-$872	114	0.45	-$1,041	0.43	-$1,444	132
HCE 3%	140,000	0.57	-$733	98	0.52	-$902	0.50	-$1,263	113
HCE 3%	160,000	0.65	-$593	86	0.59	-$762	0.57	-$1,081	99
HCE 3%	180,000	0.73	-$454	76	0.67	-$623	0.65	-$899	88
HCE 7%	60,000	0.22	-$1,291	229	0.22	-$1,363	0.20	-$1,945	264
HCE 7%	80,000	0.30	-$1,166	172	0.29	-$1,238	0.27	-$1,782	198

HCE 7%	100,000	0.37	-$1,041	137	0.36	-$1,113	0.33	-$1,619	158
HCE 7%	120,000	0.45	-$916	114	0.43	-$988	0.40	-$1,457	132
HCE 7%	140,000	0.52	-$791	98	0.50	-$863	0.47	-$1,294	113
HCE 7%	160,000	0.60	-$666	86	0.57	-$739	0.53	-$1,131	99
HCE 7%	180,000	0.67	-$542	76	0.65	-$614	0.60	-$969	88

Table 65. Carrier and Societal BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial ACC Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**BCR**	**NPV**	**Payback Period (0%)**	**BCR**	**NPV**	**BCR**	**NPV**	**Payback Period (0 %)**
LCE 3%	60,000	0.24	-$1,290	229	0.22	-$1,459	0.35	-$1,019	163
LCE 3%	80,000	0.33	-$1,151	172	0.30	-$1,320	0.46	-$837	122
LCE 3%	100,000	0.41	-$1,012	137	0.37	-$1,180	0.58	-$655	98
LCE 3%	120,000	0.49	-$872	114	0.45	-$1,041	0.70	-$474	82
LCE 3%	140,000	0.57	-$733	98	0.52	-$902	0.81	-$292	70
LCE 3%	160,000	0.65	-$593	86	0.59	-$762	0.93	-$110	61
LCE 3%	180,000	0.73	-$454	76	0.67	-$623	1.05	$72	54
LCE 7%	60,000	0.22	-$1,291	229	0.22	-1363	0.33	-$1,010	163
LCE 7%	80,000	0.30	-$1,166	172	0.29	-1238	0.43	-$847	122
LCE 7%	100,000	0.37	-$1,041	137	0.36	-1113	0.54	-$685	98
LCE 7%	120,000	0.45	-$916	114	0.43	-988	0.65	-$522	82
LCE 7%	140,000	0.52	-$791	98	0.50	-863	0.76	-$359	70
LCE 7%	160,000	0.60	-$666	86	0.57	-739	0.87	-$197	61
LCE 7%	180,000	0.67	-$542	76	0.65	-614	0.98	-$34	54
ACE 3%	60,000	0.21	-$1,611	272	0.19	-$1,813	0.27	-$1,504	213
ACE 3%	80,000	0.27	-$1,471	204	0.25	-$1,674	0.35	-$1,322	160
ACE 3%	100,000	0.34	-$1,332	163	0.31	-$1,535	0.44	-$1,141	128
ACE 3%	120,000	0.41	-$1,192	136	0.37	-$1,395	0.53	-$959	107
ACE 3%	140,000	0.48	-$1,053	116	0.44	-$1,256	0.62	-$777	91
ACE 3%	160,000	0.55	-$913	102	0.50	-$1,116	0.71	-$596	80
ACE 3%	180,000	0.62	-$774	91	0.56	-$977	0.80	-$414	71
ACE 7%	60,000	0.19	-$1,604	272	0.18	-$1,813	0.25	-$1,477	213
ACE 7%	80,000	0.25	-$1,480	204	0.24	-$1,674	0.33	-$1,315	160
ACE 7%	100,000	0.32	-$1,355	163	0.30	-$1,535	0.41	-$1,152	128
ACE 7%	120,000	0.38	-$1,230	136	0.36	-$1,395	0.50	-$989	107
ACE 7%	140,000	0.44	-$1,105	116	0.42	-$1,256	0.58	-$827	91
ACE 7%	160,000	0.50	-$980	102	0.48	-$1,116	0.66	-$664	80
ACE 7%	180,000	0.57	-$855	91	0.54	-$977	0.74	-$501	71
HCE 3%	60,000	0.18	-$1,931	314	0.16	-$2,168	0.22	-$1,990	264
HCE 3%	80,000	0.24	-$1,791	236	0.22	-$2,028	0.29	-$1,808	198
HCE 3%	100,000	0.30	-$1,652	189	0.27	-$1,889	0.36	-$1,626	158
HCE 3%	120,000	0.36	-$1,513	157	0.32	-$1,749	0.43	-$1,444	132
HCE 3%	140,000	0.42	-$1,373	135	0.38	-$1,610	0.50	-$1,263	113
HCE 3%	160,000	0.47	-$1,234	118	0.43	-$1,470	0.57	-$1,081	99
HCE 3%	180,000	0.53	-$1,094	105	0.49	-$1,331	0.65	-$899	88
HCE 7%	60,000	0.16	-$1,918	314	0.16	-$2,019	0.20	-$1,945	264
HCE 7%	80,000	0.22	-$1,793	236	0.21	-$1,895	0.27	-$1,782	198
HCE 7%	100,000	0.27	-$1,669	189	0.26	-$1,770	0.33	-$1,619	158
HCE 7%	120,000	0.33	-$1,544	157	0.31	-$1,645	0.40	-$1,457	132
HCE 7%	140,000	0.38	-$1,419	135	0.37	-$1,520	0.47	-$1,294	113
HCE 7%	160,000	0.44	-$1,294	118	0.42	-$1,395	0.53	-$1,131	99
HCE 7%	180,000	0.49	-$1,169	105	0.47	-$1,270	0.60	-$969	88

Table 66. Carrier and Societal BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial CMBS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	BCR	NPV	Payback Period (0%)	BCR	NPV	BCR	NPV	Payback Period (0%)
LCE 3%	60,000	0.55	-$826	108	0.47	-$995	0.45	-$1,384	125
LCE 3%	80,000	0.74	-$531	81	0.63	-$700	0.61	-$1,000	94
LCE 3%	100,000	0.92	-$237	65	0.78	-$406	0.76	-$617	75
LCE 3%	120,000	1.11	$58	54	0.94	-$111	0.91	-$233	62
LCE 3%	140,000	1.29	$352	46	1.10	$183	1.06	$151	54
LCE 3%	160,000	1.48	$646	41	1.25	$477	1.21	$534	47
LCE 3%	180,000	1.66	$941	36	1.41	$772	1.36	$918	42
LCE 7%	60,000	0.47	-$875	108	0.46	-947	0.42	-$1,402	125
LCE 7%	80,000	0.63	-$611	81	0.61	-683	0.56	-$1,059	94
LCE 7%	100,000	0.79	-$347	65	0.76	-420	0.71	-$715	75
LCE 7%	120,000	0.95	-$84	54	0.91	-156	0.85	-$372	62
LCE 7%	140,000	1.11	$180	46	1.06	108	0.99	-$29	54
LCE 7%	160,000	1.27	$443	41	1.21	371	1.13	$315	47
LCE 7%	180,000	1.42	$707	36	1.37	635	1.27	$658	42
ACE 3%	60,000	0.44	-$1,146	129	0.40	-$1,349	0.38	-$1,869	149
ACE 3%	80,000	0.58	-$851	96	0.53	-$1,054	0.51	-$1,486	112
ACE 3%	100,000	0.73	-$557	77	0.66	-$760	0.64	-$1,102	89
ACE 3%	120,000	0.87	-$263	64	0.79	-$466	0.76	-$718	74
ACE 3%	140,000	1.02	$32	55	0.92	-$171	0.89	-$335	64
ACE 3%	160,000	1.16	$326	48	1.06	$123	1.02	$49	56
ACE 3%	180,000	1.31	$620	43	1.19	$418	1.14	$432	50
ACE 7%	60,000	0.40	-$1,188	129	0.38	-$1,349	0.36	-$1,870	149
ACE 7%	80,000	0.53	-$925	96	0.51	-$1,054	0.47	-$1,526	112
ACE 7%	100,000	0.67	-$661	77	0.64	-$760	0.59	-$1,183	89
ACE 7%	120,000	0.80	-$398	64	0.77	-$466	0.71	-$839	74
ACE 7%	140,000	0.93	-$134	55	0.89	-$171	0.83	-$496	64
ACE 7%	160,000	1.07	$129	48	1.02	$123	0.95	-$152	56
ACE 7%	180,000	1.20	$393	43	1.15	$418	1.07	$191	50
HCE 3%	60,000	0.38	-$1,466	149	0.34	-$1,703	0.33	-$2,355	173
HCE 3%	80,000	0.50	-$1,172	112	0.46	-$1,408	0.44	-$1,971	130
HCE 3%	100,000	0.63	-$877	89	0.57	-$1,114	0.55	-$1,587	104
HCE 3%	120,000	0.75	-$583	74	0.68	-$820	0.66	-$1,204	86
HCE 3%	140,000	0.88	-$289	64	0.80	-$525	0.77	-$820	74
HCE 3%	160,000	1.00	$6	56	0.91	-$231	0.88	-$437	65
HCE 3%	180,000	1.13	$300	50	1.02	$63	0.98	-$53	58
HCE 7%	60,000	0.34	-$1,502	149	0.33	-$1,603	0.31	-$2,337	173
HCE 7%	80,000	0.46	-$1,239	112	0.44	-$1,340	0.41	-$1,993	130
HCE 7%	100,000	0.57	-$975	89	0.55	-$1,076	0.51	-$1,650	104
HCE 7%	120,000	0.69	-$711	74	0.66	-$813	0.61	-$1,307	86
HCE 7%	140,000	0.80	-$448	64	0.77	-$549	0.71	-$963	74
HCE 7%	160,000	0.92	-$184	56	0.88	-$286	0.82	-$620	65
HCE 7%	180,000	1.03	$79	50	0.99	-$22	0.92	-$276	58

Table 67. Carrier and Societal Extended Service (7 Years) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	BCR	NPV	Payback Period (0%)	BCR	NPV	BCR	NPV	Payback Period (0 %)
LCE 3%	60,000	0.51	-$538	150	0.47	-$639	0.46	-$861	168
LCE 3%	80,000	0.69	-$348	112	0.63	-$450	0.62	-$614	126
LCE 3%	100,000	0.86	-$159	90	0.78	-$260	0.77	-$367	101
LCE 3%	120,000	1.03	$31	75	0.94	-$70	0.93	-$119	84
LCE 3%	140,000	1.20	$221	64	1.10	$119	1.08	$128	72
LCE 3%	160,000	1.37	$411	56	1.26	$309	1.23	$375	63
LCE 3%	180,000	1.54	$600	50	1.41	$499	1.39	$622	56
LCE 7%	60,000	0.46	-$576	150	0.44	-619	0.42	-$887	168
LCE 7%	80,000	0.61	-$412	112	0.59	-455	0.56	-$673	126
LCE 7%	100,000	0.77	-$247	90	0.74	-291	0.70	-$459	101
LCE 7%	120,000	0.92	-$83	75	0.89	-127	0.84	-$245	84
LCE 7%	140,000	1.08	$81	64	1.03	37	0.98	-$32	72
LCE 7%	160,000	1.23	$245	56	1.18	202	1.12	$182	63
LCE 7%	180,000	1.38	$409	50	1.33	366	1.26	$396	56
ACE 3%	60,000	0.40	-$858	192	0.36	-$993	0.36	-$1,346	218
ACE 3%	80,000	0.53	-$668	144	0.49	-$804	0.47	-$1,099	164
ACE 3%	100,000	0.66	-$479	115	0.61	-$614	0.59	-$852	131
ACE 3%	120,000	0.80	-$289	96	0.73	-$424	0.71	-$605	109
ACE 3%	140,000	0.93	-$99	82	0.85	-$235	0.83	-$358	94
ACE 3%	160,000	1.06	$90	72	0.97	-$45	0.95	-$110	82
ACE 3%	180,000	1.20	$280	64	1.09	$145	1.07	$137	73
ACE 7%	60,000	0.36	-$889	192	0.34	-$993	0.32	-$1,354	218
ACE 7%	80,000	0.48	-$725	144	0.46	-$804	0.43	-$1,140	164
ACE 7%	100,000	0.59	-$561	115	0.57	-$614	0.54	-$927	131
ACE 7%	120,000	0.71	-$397	96	0.68	-$424	0.64	-$713	109
ACE 7%	140,000	0.83	-$233	82	0.80	-$235	0.75	-$499	94
ACE 7%	160,000	0.95	-$69	72	0.91	-$45	0.86	-$285	82
ACE 7%	180,000	1.07	$95	64	1.03	$145	0.96	-$71	73
HCE 3%	60,000	0.33	-$1,178	235	0.30	-$1,347	0.29	-$1,832	269
HCE 3%	80,000	0.43	-$989	176	0.40	-$1,158	0.38	-$1,585	201
HCE 3%	100,000	0.54	-$799	141	0.49	-$968	0.48	-$1,337	161
HCE 3%	120,000	0.65	-$609	118	0.59	-$778	0.58	-$1,090	134
HCE 3%	140,000	0.76	-$420	101	0.69	-$589	0.67	-$843	115
HCE 3%	160,000	0.87	-$230	88	0.79	-$399	0.77	-$596	101
HCE 3%	180,000	0.98	-$40	78	0.89	-$209	0.86	-$349	90
HCE 7%	60,000	0.29	-$1,203	235	0.28	-$1,275	0.26	-$1,821	269
HCE 7%	80,000	0.39	-$1,039	176	0.37	-$1,111	0.35	-$1,608	201
HCE 7%	100,000	0.48	-$875	141	0.46	-$947	0.43	-$1,394	161
HCE 7%	120,000	0.58	-$711	118	0.56	-$783	0.52	-$1,180	134
HCE 7%	140,000	0.68	-$547	101	0.65	-$619	0.61	-$966	115
HCE 7%	160,000	0.77	-$383	88	0.74	-$455	0.69	-$752	101
HCE 7%	180,000	0.87	-$219	78	0.84	-$291	0.78	-$538	90

Table 68. Carrier and Societal Extended Service (10 Years) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**BCR**	**NPV**	**Payback Period (0%)**	**BCR**	**NPV**	**BCR**	**NPV**	**Payback Period (0 %)**
LCE 3%	60,000	0.67	-$382	159	0.62	-$483	0.61	-$641	175
LCE 3%	80,000	0.89	-$122	119	0.82	-$223	0.82	-$303	131
LCE 3%	100,000	1.12	$138	95	1.03	$36	1.02	$36	105
LCE 3%	120,000	1.34	$397	79	1.23	$296	1.23	$374	87
LCE 3%	140,000	1.57	$657	68	1.44	$556	1.43	$713	75
LCE 3%	160,000	1.79	$917	60	1.65	$815	1.63	$1,051	66
LCE 3%	180,000	2.01	$1,177	53	1.85	$1,075	1.84	$1,390	58
LCE 7%	60,000	0.58	-$464	159	0.56	-507	0.53	-$730	175
LCE 7%	80,000	0.77	-$250	119	0.74	-293	0.71	-$451	131
LCE 7%	100,000	0.97	-$36	95	0.93	-79	0.89	-$173	105
LCE 7%	120,000	1.16	$178	79	1.12	134	1.07	$106	87
LCE 7%	140,000	1.35	$392	68	1.30	348	1.25	$385	75
LCE 7%	160,000	1.55	$605	60	1.49	562	1.42	$664	66
LCE 7%	180,000	1.74	$819	53	1.68	776	1.60	$942	58
ACE 3%	60,000	0.53	-$702	202	0.48	-$837	0.47	-$1,127	225
ACE 3%	80,000	0.70	-$442	151	0.64	-$578	0.63	-$788	169
ACE 3%	100,000	0.88	-$183	121	0.80	-$318	0.79	-$450	135
ACE 3%	120,000	1.05	$77	101	0.96	-$58	0.95	-$111	113
ACE 3%	140,000	1.23	$337	86	1.12	$202	1.11	$227	97
ACE 3%	160,000	1.40	$597	76	1.29	$461	1.26	$566	84
ACE 3%	180,000	1.58	$856	67	1.45	$721	1.42	$904	75
ACE 7%	60,000	0.45	-$778	202	0.43	-$837	0.41	-$1,197	225
ACE 7%	80,000	0.60	-$564	151	0.58	-$578	0.55	-$918	169
ACE 7%	100,000	0.75	-$350	121	0.72	-$318	0.69	-$640	135
ACE 7%	120,000	0.90	-$136	101	0.87	-$58	0.82	-$361	113
ACE 7%	140,000	1.05	$78	86	1.01	$202	0.96	-$82	97
ACE 7%	160,000	1.21	$292	76	1.16	$461	1.10	$196	84
ACE 7%	180,000	1.36	$505	67	1.30	$721	1.23	$475	75
HCE 3%	60,000	0.43	-$1,022	244	0.40	-$1,191	0.39	-$1,612	276
HCE 3%	80,000	0.58	-$763	183	0.53	-$932	0.52	-$1,274	207
HCE 3%	100,000	0.72	-$503	147	0.66	-$672	0.64	-$935	165
HCE 3%	120,000	0.87	-$243	122	0.79	-$412	0.77	-$597	138
HCE 3%	140,000	1.01	$17	105	0.92	-$152	0.90	-$258	118
HCE 3%	160,000	1.15	$276	92	1.05	$107	1.03	$80	103
HCE 3%	180,000	1.30	$536	81	1.19	$367	1.16	$419	92
HCE 7%	60,000	0.37	-$1,091	244	0.36	-$1,164	0.33	-$1,664	276
HCE 7%	80,000	0.49	-$878	183	0.47	-$950	0.45	-$1,386	207
HCE 7%	100,000	0.62	-$664	147	0.59	-$736	0.56	-$1,107	165
HCE 7%	120,000	0.74	-$450	122	0.71	-$522	0.67	-$828	138
HCE 7%	140,000	0.86	-$236	105	0.83	-$308	0.78	-$550	118
HCE 7%	160,000	0.99	-$22	92	0.95	-$94	0.89	-$271	103
HCE 7%	180,000	1.11	$192	81	1.07	$120	1.00	$8	92

Table 69. Carrier High Deductible ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**BCR**	**NPV**	**Payback Period (0%)**	**BCR**	**NPV**	**BCR**	**NPV**	**Payback Period (0 %)**
LCE 3%	60,000	0.17	-$886	330	0.16	-$988	0.35	-$1,019	163
LCE 3%	80,000	0.23	-$826	248	0.21	-$927	0.46	-$837	122
LCE 3%	100,000	0.28	-$765	198	0.26	-$867	0.58	-$655	98
LCE 3%	120,000	0.34	-$704	165	0.31	-$806	0.70	-$474	82
LCE 3%	140,000	0.40	-$644	141	0.36	-$745	0.81	-$292	70
LCE 3%	160,000	0.45	-$583	124	0.41	-$685	0.93	-$110	61
LCE 3%	180,000	0.51	-$523	110	0.47	-$624	1.05	$72	54
LCE 7%	60,000	0.16	-$875	330	0.15	-918	0.33	-$1,010	163
LCE 7%	80,000	0.21	-$820	248	0.20	-864	0.43	-$847	122
LCE 7%	100,000	0.26	-$766	198	0.25	-810	0.54	-$685	98
LCE 7%	120,000	0.31	-$712	165	0.30	-755	0.65	-$522	82
LCE 7%	140,000	0.37	-$658	141	0.35	-701	0.76	-$359	70
LCE 7%	160,000	0.42	-$603	124	0.40	-647	0.87	-$197	61
LCE 7%	180,000	0.47	-$549	110	0.45	-592	0.98	-$34	54
ACE 3%	60,000	0.13	-$1,207	428	0.12	-$1,342	0.27	-$1,504	213
ACE 3%	80,000	0.17	-$1,146	321	0.16	-$1,281	0.35	-$1,322	160
ACE 3%	100,000	0.22	-$1,085	257	0.20	-$1,221	0.44	-$1,141	128
ACE 3%	120,000	0.26	-$1,025	214	0.24	-$1,160	0.53	-$959	107
ACE 3%	140,000	0.31	-$964	184	0.28	-$1,099	0.62	-$777	91
ACE 3%	160,000	0.35	-$903	161	0.32	-$1,039	0.71	-$596	80
ACE 3%	180,000	0.39	-$843	143	0.36	-$978	0.80	-$414	71
ACE 7%	60,000	0.12	-$1,189	428	0.12	-$1,342	0.25	-$1,477	213
ACE 7%	80,000	0.16	-$1,134	321	0.15	-$1,281	0.33	-$1,315	160
ACE 7%	100,000	0.20	-$1,080	257	0.19	-$1,221	0.41	-$1,152	128
ACE 7%	120,000	0.24	-$1,026	214	0.23	-$1,160	0.50	-$989	107
ACE 7%	140,000	0.28	-$971	184	0.27	-$1,099	0.58	-$827	91
ACE 7%	160,000	0.32	-$917	161	0.31	-$1,039	0.66	-$664	80
ACE 7%	180,000	0.36	-$863	143	0.35	-$978	0.74	-$501	71
HCE 3%	60,000	0.11	-$1,527	526	0.10	-$1,696	0.22	-$1,990	264
HCE 3%	80,000	0.14	-$1,466	395	0.13	-$1,635	0.29	-$1,808	198
HCE 3%	100,000	0.18	-$1,406	316	0.16	-$1,575	0.36	-$1,626	158
HCE 3%	120,000	0.21	-$1,345	263	0.19	-$1,514	0.43	-$1,444	132
HCE 3%	140,000	0.25	-$1,284	226	0.23	-$1,453	0.50	-$1,263	113
HCE 3%	160,000	0.28	-$1,224	197	0.26	-$1,393	0.57	-$1,081	99
HCE 3%	180,000	0.32	-$1,163	175	0.29	-$1,332	0.65	-$899	88
HCE 7%	60,000	0.10	-$1,502	526	0.09	-$1,574	0.20	-$1,945	264
HCE 7%	80,000	0.13	-$1,448	395	0.12	-$1,520	0.27	-$1,782	198
HCE 7%	100,000	0.16	-$1,394	316	0.16	-$1,466	0.33	-$1,619	158
HCE 7%	120,000	0.20	-$1,339	263	0.19	-$1,412	0.40	-$1,457	132
HCE 7%	140,000	0.23	-$1,285	226	0.22	-$1,357	0.47	-$1,294	113
HCE 7%	160,000	0.26	-$1,231	197	0.25	-$1,303	0.53	-$1,131	99
HCE 7%	180,000	0.29	-$1,177	175	0.28	-$1,249	0.60	-$969	88

Table 70. Carrier High Deductible ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial CMBS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	0.22	-$1,325	249	0.20	-$1,494	0.45	-$1,384	125
LCE 3%	80,000	0.30	-$1,197	187	0.27	-$1,366	0.61	-$1,000	94
LCE 3%	100,000	0.37	-$1,069	150	0.34	-$1,238	0.76	-$617	75
LCE 3%	120,000	0.45	-$941	125	0.41	-$1,110	0.91	-$233	62
LCE 3%	140,000	0.52	-$813	107	0.48	-$982	1.06	$151	54
LCE 3%	160,000	0.60	-$685	94	0.55	-$854	1.21	$534	47
LCE 3%	180,000	0.67	-$557	83	0.61	-$726	1.36	$918	42
LCE 7%	60,000	0.21	-$1,321	249	0.20	-1394	0.42	-$1,402	125
LCE 7%	80,000	0.28	-$1,207	187	0.26	-1279	0.56	-$1,059	94
LCE 7%	100,000	0.34	-$1,092	150	0.33	-1164	0.71	-$715	75
LCE 7%	120,000	0.41	-$978	125	0.40	-1050	0.85	-$372	62
LCE 7%	140,000	0.48	-$863	107	0.46	-935	0.99	-$29	54
LCE 7%	160,000	0.55	-$748	94	0.53	-821	1.13	$315	47
LCE 7%	180,000	0.62	-$634	83	0.59	-706	1.27	$658	42
ACE 3%	60,000	0.19	-$1,645	296	0.17	-$1,848	0.38	-$1,869	149
ACE 3%	80,000	0.25	-$1,517	222	0.23	-$1,720	0.51	-$1,486	112
ACE 3%	100,000	0.32	-$1,389	178	0.29	-$1,592	0.64	-$1,102	89
ACE 3%	120,000	0.38	-$1,261	148	0.34	-$1,464	0.76	-$718	74
ACE 3%	140,000	0.44	-$1,133	127	0.40	-$1,336	0.89	-$335	64
ACE 3%	160,000	0.50	-$1,005	111	0.46	-$1,208	1.02	$49	56
ACE 3%	180,000	0.57	-$877	99	0.52	-$1,080	1.14	$432	50
ACE 7%	60,000	0.17	-$1,635	296	0.17	-$1,848	0.36	-$1,870	149
ACE 7%	80,000	0.23	-$1,521	222	0.22	-$1,720	0.47	-$1,526	112
ACE 7%	100,000	0.29	-$1,406	178	0.28	-$1,592	0.59	-$1,183	89
ACE 7%	120,000	0.35	-$1,291	148	0.33	-$1,464	0.71	-$839	74
ACE 7%	140,000	0.41	-$1,177	127	0.39	-$1,336	0.83	-$496	64
ACE 7%	160,000	0.46	-$1,062	111	0.44	-$1,208	0.95	-$152	56
ACE 7%	180,000	0.52	-$948	99	0.50	-$1,080	1.07	$191	50
HCE 3%	60,000	0.16	-$1,965	342	0.15	-$2,202	0.33	-$2,355	173
HCE 3%	80,000	0.22	-$1,837	257	0.20	-$2,074	0.44	-$1,971	130
HCE 3%	100,000	0.27	-$1,709	205	0.25	-$1,946	0.55	-$1,587	104
HCE 3%	120,000	0.33	-$1,581	171	0.30	-$1,818	0.66	-$1,204	86
HCE 3%	140,000	0.38	-$1,453	147	0.35	-$1,690	0.77	-$820	74
HCE 3%	160,000	0.44	-$1,325	128	0.40	-$1,562	0.88	-$437	65
HCE 3%	180,000	0.49	-$1,197	114	0.45	-$1,434	0.98	-$53	58
HCE 7%	60,000	0.15	-$1,949	342	0.14	-$2,050	0.31	-$2,337	173
HCE 7%	80,000	0.20	-$1,834	257	0.19	-$1,936	0.41	-$1,993	130
HCE 7%	100,000	0.25	-$1,720	205	0.24	-$1,821	0.51	-$1,650	104
HCE 7%	120,000	0.30	-$1,605	171	0.29	-$1,706	0.61	-$1,307	86
HCE 7%	140,000	0.35	-$1,491	147	0.34	-$1,592	0.71	-$963	74
HCE 7%	160,000	0.40	-$1,376	128	0.38	-$1,477	0.82	-$620	65
HCE 7%	180,000	0.45	-$1,261	114	0.43	-$1,363	0.92	-$276	58

Table 71. Carrier Low Deductible ($5,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	BCR	NPV	Payback Period (0%)	BCR	NPV	BCR	NPV	Payback Period (0 %)
LCE 3%	60,000	0.07	-$998	850	0.06	-$1,099	0.35	-$1,019	163
LCE 3%	80,000	0.09	-$974	638	0.08	-$1,076	0.46	-$837	122
LCE 3%	100,000	0.11	-$951	510	0.10	-$1,052	0.58	-$655	98
LCE 3%	120,000	0.13	-$927	425	0.12	-$1,028	0.70	-$474	82
LCE 3%	140,000	0.15	-$904	364	0.14	-$1,005	0.81	-$292	70
LCE 3%	160,000	0.18	-$880	319	0.16	-$981	0.93	-$110	61
LCE 3%	180,000	0.20	-$856	283	0.18	-$958	1.05	$72	54
LCE 7%	60,000	0.06	-$974	850	0.06	-1018	0.33	-$1,010	163
LCE 7%	80,000	0.08	-$953	638	0.08	-997	0.43	-$847	122
LCE 7%	100,000	0.10	-$932	510	0.10	-976	0.54	-$685	98
LCE 7%	120,000	0.12	-$911	425	0.12	-955	0.65	-$522	82
LCE 7%	140,000	0.14	-$890	364	0.14	-933	0.76	-$359	70
LCE 7%	160,000	0.16	-$869	319	0.16	-912	0.87	-$197	61
LCE 7%	180,000	0.18	-$848	283	0.18	-891	0.98	-$34	54
ACE 3%	60,000	0.05	-$1,318	1103	0.05	-$1,453	0.27	-$1,504	213
ACE 3%	80,000	0.07	-$1,294	827	0.06	-$1,430	0.35	-$1,322	160
ACE 3%	100,000	0.08	-$1,271	662	0.08	-$1,406	0.44	-$1,141	128
ACE 3%	120,000	0.10	-$1,247	552	0.09	-$1,383	0.53	-$959	107
ACE 3%	140,000	0.12	-$1,224	473	0.11	-$1,359	0.62	-$777	91
ACE 3%	160,000	0.14	-$1,200	414	0.12	-$1,335	0.71	-$596	80
ACE 3%	180,000	0.15	-$1,177	368	0.14	-$1,312	0.80	-$414	71
ACE 7%	60,000	0.05	-$1,288	1103	0.04	-$1,453	0.25	-$1,477	213
ACE 7%	80,000	0.06	-$1,267	827	0.06	-$1,430	0.33	-$1,315	160
ACE 7%	100,000	0.08	-$1,246	662	0.07	-$1,406	0.41	-$1,152	128
ACE 7%	120,000	0.09	-$1,225	552	0.09	-$1,383	0.50	-$989	107
ACE 7%	140,000	0.11	-$1,204	473	0.10	-$1,359	0.58	-$827	91
ACE 7%	160,000	0.12	-$1,183	414	0.12	-$1,335	0.66	-$664	80
ACE 7%	180,000	0.14	-$1,162	368	0.13	-$1,312	0.74	-$501	71
HCE 3%	60,000	0.04	-$1,638	1356	0.04	-$1,807	0.22	-$1,990	264
HCE 3%	80,000	0.06	-$1,615	1017	0.05	-$1,784	0.29	-$1,808	198
HCE 3%	100,000	0.07	-$1,591	814	0.06	-$1,760	0.36	-$1,626	158
HCE 3%	120,000	0.08	-$1,568	678	0.08	-$1,736	0.43	-$1,444	132
HCE 3%	140,000	0.10	-$1,544	581	0.09	-$1,713	0.50	-$1,263	113
HCE 3%	160,000	0.11	-$1,520	509	0.10	-$1,689	0.57	-$1,081	99
HCE 3%	180,000	0.12	-$1,497	452	0.11	-$1,666	0.65	-$899	88
HCE 7%	60,000	0.04	-$1,602	1356	0.04	-$1,674	0.20	-$1,945	264
HCE 7%	80,000	0.05	-$1,581	1017	0.05	-$1,653	0.27	-$1,782	198
HCE 7%	100,000	0.06	-$1,560	814	0.06	-$1,632	0.33	-$1,619	158
HCE 7%	120,000	0.08	-$1,539	678	0.07	-$1,611	0.40	-$1,457	132
HCE 7%	140,000	0.09	-$1,518	581	0.08	-$1,590	0.47	-$1,294	113
HCE 7%	160,000	0.10	-$1,497	509	0.10	-$1,569	0.53	-$1,131	99
HCE 7%	180,000	0.11	-$1,476	452	0.11	-$1,548	0.60	-$969	88

Table 72. Carrier Low Deductible ($5,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial CMBS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	0.09	-$1,560	642	0.08	-$1,729	0.45	-$1,384	125
LCE 3%	80,000	0.12	-$1,510	482	0.11	-$1,679	0.61	-$1,000	94
LCE 3%	100,000	0.15	-$1,460	385	0.13	-$1,629	0.76	-$617	75
LCE 3%	120,000	0.17	-$1,411	321	0.16	-$1,580	0.91	-$233	62
LCE 3%	140,000	0.20	-$1,361	275	0.19	-$1,530	1.06	$151	54
LCE 3%	160,000	0.23	-$1,311	241	0.21	-$1,480	1.21	$534	47
LCE 3%	180,000	0.26	-$1,262	214	0.24	-$1,430	1.36	$918	42
LCE 7%	60,000	0.08	-$1,532	642	0.08	-1604	0.42	-$1,402	125
LCE 7%	80,000	0.11	-$1,487	482	0.10	-1559	0.56	-$1,059	94
LCE 7%	100,000	0.13	-$1,443	385	0.13	-1515	0.71	-$715	75
LCE 7%	120,000	0.16	-$1,398	321	0.15	-1470	0.85	-$372	62
LCE 7%	140,000	0.19	-$1,354	275	0.18	-1426	0.99	-$29	54
LCE 7%	160,000	0.21	-$1,309	241	0.20	-1381	1.13	$315	47
LCE 7%	180,000	0.24	-$1,265	214	0.23	-1337	1.27	$658	42
ACE 3%	60,000	0.07	-$1,880	762	0.07	-$2,083	0.38	-$1,869	149
ACE 3%	80,000	0.10	-$1,830	572	0.09	-$2,033	0.51	-$1,486	112
ACE 3%	100,000	0.12	-$1,781	457	0.11	-$1,983	0.64	-$1,102	89
ACE 3%	120,000	0.15	-$1,731	381	0.13	-$1,934	0.76	-$718	74
ACE 3%	140,000	0.17	-$1,681	327	0.16	-$1,884	0.89	-$335	64
ACE 3%	160,000	0.20	-$1,632	286	0.18	-$1,834	1.02	$49	56
ACE 3%	180,000	0.22	-$1,582	254	0.20	-$1,785	1.14	$432	50
ACE 7%	60,000	0.07	-$1,846	762	0.06	-$2,083	0.36	-$1,870	149
ACE 7%	80,000	0.09	-$1,801	572	0.09	-$2,033	0.47	-$1,526	112
ACE 7%	100,000	0.11	-$1,757	457	0.11	-$1,983	0.59	-$1,183	89
ACE 7%	120,000	0.13	-$1,712	381	0.13	-$1,934	0.71	-$839	74
ACE 7%	140,000	0.16	-$1,668	327	0.15	-$1,884	0.83	-$496	64
ACE 7%	160,000	0.18	-$1,623	286	0.17	-$1,834	0.95	-$152	56
ACE 7%	180,000	0.20	-$1,579	254	0.19	-$1,785	1.07	$191	50
HCE 3%	60,000	0.06	-$2,200	882	0.06	-$2,437	0.33	-$2,355	173
HCE 3%	80,000	0.08	-$2,150	662	0.08	-$2,387	0.44	-$1,971	130
HCE 3%	100,000	0.11	-$2,101	529	0.10	-$2,338	0.55	-$1,587	104
HCE 3%	120,000	0.13	-$2,051	441	0.12	-$2,288	0.66	-$1,204	86
HCE 3%	140,000	0.15	-$2,001	378	0.13	-$2,238	0.77	-$820	74
HCE 3%	160,000	0.17	-$1,952	331	0.15	-$2,188	0.88	-$437	65
HCE 3%	180,000	0.19	-$1,902	294	0.17	-$2,139	0.98	-$53	58
HCE 7%	60,000	0.06	-$2,159	882	0.06	-$2,261	0.31	-$2,337	173
HCE 7%	80,000	0.08	-$2,115	662	0.07	-$2,216	0.41	-$1,993	130
HCE 7%	100,000	0.10	-$2,070	529	0.09	-$2,172	0.51	-$1,650	104
HCE 7%	120,000	0.12	-$2,026	441	0.11	-$2,127	0.61	-$1,307	86
HCE 7%	140,000	0.14	-$1,981	378	0.13	-$2,083	0.71	-$963	74
HCE 7%	160,000	0.16	-$1,937	331	0.15	-$2,038	0.82	-$620	65
HCE 7%	180,000	0.17	-$1,892	294	0.17	-$1,994	0.92	-$276	58

Table 73. Carrier High-Value Cargo ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	BCR	NPV	Payback Period (0%)	BCR	NPV	BCR	NPV	Payback Period (0 %)
LCE 3%	60,000	0.50	-$533	112	0.46	-$634	0.35	-$1,019	163
LCE 3%	80,000	0.67	-$354	84	0.61	-$455	0.46	-$837	122
LCE 3%	100,000	0.84	-$175	67	0.76	-$277	0.58	-$655	98
LCE 3%	120,000	1.00	$3	56	0.92	-$98	0.70	-$474	82
LCE 3%	140,000	1.17	$182	48	1.07	$80	0.81	-$292	70
LCE 3%	160,000	1.34	$360	42	1.22	$259	0.93	-$110	61
LCE 3%	180,000	1.50	$539	37	1.37	$437	1.05	$72	54
LCE 7%	60,000	0.46	-$558	112	0.44	-601	0.33	-$1,010	163
LCE 7%	80,000	0.62	-$398	84	0.59	-442	0.43	-$847	122
LCE 7%	100,000	0.77	-$238	67	0.74	-282	0.54	-$685	98
LCE 7%	120,000	0.92	-$78	56	0.89	-122	0.65	-$522	82
LCE 7%	140,000	1.08	$81	48	1.04	38	0.76	-$359	70
LCE 7%	160,000	1.23	$241	42	1.18	198	0.87	-$197	61
LCE 7%	180,000	1.39	$401	37	1.33	358	0.98	-$34	54
ACE 3%	60,000	0.39	-$853	145	0.35	-$988	0.27	-$1,504	213
ACE 3%	80,000	0.51	-$674	109	0.47	-$810	0.35	-$1,322	160
ACE 3%	100,000	0.64	-$496	87	0.59	-$631	0.44	-$1,141	128
ACE 3%	120,000	0.77	-$317	73	0.70	-$452	0.53	-$959	107
ACE 3%	140,000	0.90	-$139	62	0.82	-$274	0.62	-$777	91
ACE 3%	160,000	1.03	$40	55	0.94	-$95	0.71	-$596	80
ACE 3%	180,000	1.16	$218	48	1.05	$83	0.80	-$414	71
ACE 7%	60,000	0.35	-$872	145	0.34	-$988	0.25	-$1,477	213
ACE 7%	80,000	0.47	-$712	109	0.45	-$810	0.33	-$1,315	160
ACE 7%	100,000	0.59	-$552	87	0.57	-$631	0.41	-$1,152	128
ACE 7%	120,000	0.71	-$392	73	0.68	-$452	0.50	-$989	107
ACE 7%	140,000	0.83	-$232	62	0.79	-$274	0.58	-$827	91
ACE 7%	160,000	0.95	-$73	55	0.91	-$95	0.66	-$664	80
ACE 7%	180,000	1.06	$87	48	1.02	$83	0.74	-$501	71
HCE 3%	60,000	0.31	-$1,173	179	0.29	-$1,342	0.22	-$1,990	264
HCE 3%	80,000	0.42	-$995	134	0.38	-$1,163	0.29	-$1,808	198
HCE 3%	100,000	0.52	-$816	107	0.48	-$985	0.36	-$1,626	158
HCE 3%	120,000	0.63	-$637	89	0.57	-$806	0.43	-$1,444	132
HCE 3%	140,000	0.73	-$459	77	0.67	-$628	0.50	-$1,263	113
HCE 3%	160,000	0.84	-$280	67	0.76	-$449	0.57	-$1,081	99
HCE 3%	180,000	0.94	-$102	60	0.86	-$271	0.65	-$899	88
HCE 7%	60,000	0.29	-$1,186	179	0.28	-$1,258	0.20	-$1,945	264
HCE 7%	80,000	0.38	-$1,026	134	0.37	-$1,098	0.27	-$1,782	198
HCE 7%	100,000	0.48	-$866	107	0.46	-$938	0.33	-$1,619	158
HCE 7%	120,000	0.58	-$706	89	0.55	-$778	0.40	-$1,457	132
HCE 7%	140,000	0.67	-$546	77	0.64	-$618	0.47	-$1,294	113
HCE 7%	160,000	0.77	-$386	67	0.74	-$458	0.53	-$1,131	99
HCE 7%	180,000	0.86	-$226	60	0.83	-$299	0.60	-$969	88

Table 74. Carrier High-Value Cargo ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial CMBS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**B/C**	**VAN**	**Payback Period (0%)**	**B/C**	**VAN**	**B/C**	**VAN**	**Payback Period (0 %)**
LCE 3%	60,000	0.66	-$578	85	0.60	-$747	0.45	-$1,384	125
LCE 3%	80,000	0.88	-$201	64	0.80	-$370	0.61	-$1,000	94
LCE 3%	100,000	1.10	$176	51	1.00	$7	0.76	-$617	75
LCE 3%	120,000	1.32	$553	42	1.20	$384	0.91	-$233	62
LCE 3%	140,000	1.54	$930	36	1.41	$761	1.06	$151	54
LCE 3%	160,000	1.76	$1,307	32	1.61	$1,138	1.21	$534	47
LCE 3%	180,000	1.99	$1,684	28	1.81	$1,515	1.36	$918	42
LCE 7%	60,000	0.61	-$653	85	0.58	-725	0.42	-$1,402	125
LCE 7%	80,000	0.81	-$315	64	0.78	-387	0.56	-$1,059	94
LCE 7%	100,000	1.01	$22	51	0.97	-50	0.71	-$715	75
LCE 7%	120,000	1.22	$360	42	1.17	288	0.85	-$372	62
LCE 7%	140,000	1.42	$697	36	1.36	625	0.99	-$29	54
LCE 7%	160,000	1.62	$1,035	32	1.55	962	1.13	$315	47
LCE 7%	180,000	1.82	$1,372	28	1.75	1300	1.27	$658	42
ACE 3%	60,000	0.56	-$898	100	0.51	-$1,101	0.38	-$1,869	149
ACE 3%	80,000	0.74	-$521	75	0.68	-$724	0.51	-$1,486	112
ACE 3%	100,000	0.93	-$144	60	0.84	-$347	0.64	-$1,102	89
ACE 3%	120,000	1.11	$233	50	1.01	$30	0.76	-$718	74
ACE 3%	140,000	1.30	$610	43	1.18	$407	0.89	-$335	64
ACE 3%	160,000	1.49	$987	38	1.35	$784	1.02	$49	56
ACE 3%	180,000	1.67	$1,364	33	1.52	$1,161	1.14	$432	50
ACE 7%	60,000	0.51	-$967	100	0.49	-$1,101	0.36	-$1,870	149
ACE 7%	80,000	0.68	-$629	75	0.65	-$724	0.47	-$1,526	112
ACE 7%	100,000	0.85	-$292	60	0.82	-$347	0.59	-$1,183	89
ACE 7%	120,000	1.02	$46	50	0.98	$30	0.71	-$839	74
ACE 7%	140,000	1.19	$383	43	1.14	$407	0.83	-$496	64
ACE 7%	160,000	1.36	$721	38	1.31	$784	0.95	-$152	56
ACE 7%	180,000	1.53	$1,058	33	1.47	$1,161	1.07	$191	50
HCE 3%	60,000	0.48	-$1,218	116	0.44	-$1,455	0.33	-$2,355	173
HCE 3%	80,000	0.64	-$841	87	0.58	-$1,078	0.44	-$1,971	130
HCE 3%	100,000	0.80	-$465	70	0.73	-$701	0.55	-$1,587	104
HCE 3%	120,000	0.96	-$88	58	0.87	-$324	0.66	-$1,204	86
HCE 3%	140,000	1.12	$289	50	1.02	$53	0.77	-$820	74
HCE 3%	160,000	1.28	$666	44	1.17	$430	0.88	-$437	65
HCE 3%	180,000	1.44	$1,043	39	1.31	$807	0.98	-$53	58
HCE 7%	60,000	0.44	-$1,280	116	0.42	-$1,382	0.31	-$2,337	173
HCE 7%	80,000	0.59	-$943	87	0.56	-$1,044	0.41	-$1,993	130
HCE 7%	100,000	0.74	-$605	70	0.70	-$707	0.51	-$1,650	104
HCE 7%	120,000	0.88	-$268	58	0.85	-$369	0.61	-$1,307	86
HCE 7%	140,000	1.03	$70	50	0.99	-$32	0.71	-$963	74
HCE 7%	160,000	1.18	$407	44	1.13	$306	0.82	-$620	65
HCE 7%	180,000	1.32	$745	39	1.27	$643	0.92	-$276	58

Table 75. Carrier High-Value Cargo ($1,000,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	BCR	NPV	Payback Period (0%)	BCR	NPV	BCR	NPV	Payback Period (0 %)
LCE 3%	60,000	2.70	$1,817	21	2.47	$1,716	0.35	-$1,019	163
LCE 3%	80,000	3.60	$2,779	16	3.29	$2,677	0.46	-$837	122
LCE 3%	100,000	4.50	$3,740	12	4.11	$3,639	0.58	-$655	98
LCE 3%	120,000	5.40	$4,702	10	4.93	$4,601	0.70	-$474	82
LCE 3%	140,000	6.30	$5,664	9	5.76	$5,562	0.81	-$292	70
LCE 3%	160,000	7.20	$6,626	8	6.58	$6,524	0.93	-$110	61
LCE 3%	180,000	8.10	$7,587	7	7.40	$7,486	1.05	$72	54
LCE 7%	60,000	2.49	$1,545	21	2.39	1502	0.33	-$1,010	163
LCE 7%	80,000	3.32	$2,407	16	3.19	2363	0.43	-$847	122
LCE 7%	100,000	4.15	$3,268	12	3.98	3224	0.54	-$685	98
LCE 7%	120,000	4.98	$4,129	10	4.78	4085	0.65	-$522	82
LCE 7%	140,000	5.81	$4,990	9	5.58	4946	0.76	-$359	70
LCE 7%	160,000	6.64	$5,851	8	6.37	5807	0.87	-$197	61
LCE 7%	180,000	7.47	$6,712	7	7.17	6668	0.98	-$34	54
ACE 3%	60,000	2.08	$1,497	27	1.89	$1,361	0.27	-$1,504	213
ACE 3%	80,000	2.77	$2,458	20	2.52	$2,323	0.35	-$1,322	160
ACE 3%	100,000	3.46	$3,420	16	3.16	$3,285	0.44	-$1,141	128
ACE 3%	120,000	4.16	$4,382	13	3.79	$4,247	0.53	-$959	107
ACE 3%	140,000	4.85	$5,344	12	4.42	$5,208	0.62	-$777	91
ACE 3%	160,000	5.54	$6,305	10	5.05	$6,170	0.71	-$596	80
ACE 3%	180,000	6.23	$7,267	9	5.68	$7,132	0.80	-$414	71
ACE 7%	60,000	1.91	$1,232	27	1.83	$1,361	0.25	-$1,477	213
ACE 7%	80,000	2.55	$2,093	20	2.44	$2,323	0.33	-$1,315	160
ACE 7%	100,000	3.19	$2,954	16	3.06	$3,285	0.41	-$1,152	128
ACE 7%	120,000	3.82	$3,815	13	3.67	$4,247	0.50	-$989	107
ACE 7%	140,000	4.46	$4,676	12	4.28	$5,208	0.58	-$827	91
ACE 7%	160,000	5.10	$5,537	10	4.89	$6,170	0.66	-$664	80
ACE 7%	180,000	5.73	$6,398	9	5.50	$7,132	0.74	-$501	71
HCE 3%	60,000	1.69	$1,176	33	1.54	$1,008	0.22	-$1,990	264
HCE 3%	80,000	2.25	$2,138	25	2.05	$1,969	0.29	-$1,808	198
HCE 3%	100,000	2.81	$3,100	20	2.56	$2,931	0.36	-$1,626	158
HCE 3%	120,000	3.38	$4,062	17	3.07	$3,893	0.43	-$1,444	132
HCE 3%	140,000	3.94	$5,023	14	3.59	$4,854	0.50	-$1,263	113
HCE 3%	160,000	4.50	$5,985	12	4.10	$5,816	0.57	-$1,081	99
HCE 3%	180,000	5.07	$6,947	11	4.61	$6,778	0.65	-$899	88
HCE 7%	60,000	1.55	$918	33	1.49	$846	0.20	-$1,945	264
HCE 7%	80,000	2.07	$1,779	25	1.98	$1,707	0.27	-$1,782	198
HCE 7%	100,000	2.59	$2,640	20	2.48	$2,568	0.33	-$1,619	158
HCE 7%	120,000	3.10	$3,501	17	2.97	$3,429	0.40	-$1,457	132
HCE 7%	140,000	3.62	$4,362	14	3.47	$4,290	0.47	-$1,294	113
HCE 7%	160,000	4.14	$5,223	12	3.96	$5,151	0.53	-$1,131	99
HCE 7%	180,000	4.65	$6,084	11	4.46	$6,012	0.60	-$969	88

Table 76. Carrier High-Value Cargo ($1,000,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial CMBS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**B/C**	**VAN**	**Payback Period (0%)**	**B/C**	**VAN**	**B/C**	**VAN**	**Payback Period (0 %)**
LCE 3%	60,000	3.56	$4,382	16	3.24	$4,213	0.45	-$1,384	125
LCE 3%	80,000	4.75	$6,413	12	4.33	$6,244	0.61	-$1,000	94
LCE 3%	100,000	5.94	$8,443	9	5.41	$8,274	0.76	-$617	75
LCE 3%	120,000	7.13	$10,473	8	6.49	$10,304	0.91	-$233	62
LCE 3%	140,000	8.32	$12,503	7	7.57	$12,335	1.06	$151	54
LCE 3%	160,000	9.51	$14,534	6	8.65	$14,365	1.21	$534	47
LCE 3%	180,000	10.69	$16,564	5	9.73	$16,395	1.36	$918	42
LCE 7%	60,000	3.27	$3,788	16	3.14	3716	0.42	-$1,402	125
LCE 7%	80,000	4.37	$5,606	12	4.19	5534	0.56	-$1,059	94
LCE 7%	100,000	5.46	$7,423	9	5.23	7351	0.71	-$715	75
LCE 7%	120,000	6.55	$9,241	8	6.28	9169	0.85	-$372	62
LCE 7%	140,000	7.64	$11,059	7	7.32	10987	0.99	-$29	54
LCE 7%	160,000	8.73	$12,877	6	8.37	12805	1.13	$315	47
LCE 7%	180,000	9.82	$14,694	5	9.42	14622	1.27	$658	42
ACE 3%	60,000	3.00	$4,062	19	2.73	$3,859	0.38	-$1,869	149
ACE 3%	80,000	4.00	$6,092	14	3.64	$5,889	0.51	-$1,486	112
ACE 3%	100,000	5.00	$8,123	11	4.55	$7,920	0.64	-$1,102	89
ACE 3%	120,000	6.00	$10,153	9	5.46	$9,950	0.76	-$718	74
ACE 3%	140,000	7.00	$12,183	8	6.37	$11,980	0.89	-$335	64
ACE 3%	160,000	8.01	$14,214	7	7.28	$14,011	1.02	$49	56
ACE 3%	180,000	9.01	$16,244	6	8.19	$16,041	1.14	$432	50
ACE 7%	60,000	2.76	$3,474	19	2.64	$3,859	0.36	-$1,870	149
ACE 7%	80,000	3.67	$5,292	14	3.52	$5,889	0.47	-$1,526	112
ACE 7%	100,000	4.59	$7,110	11	4.40	$7,920	0.59	-$1,183	89
ACE 7%	120,000	5.51	$8,927	9	5.28	$9,950	0.71	-$839	74
ACE 7%	140,000	6.43	$10,745	8	6.16	$11,980	0.83	-$496	64
ACE 7%	160,000	7.35	$12,563	7	7.04	$14,011	0.95	-$152	56
ACE 7%	180,000	8.27	$14,381	6	7.92	$16,041	1.07	$191	50
HCE 3%	60,000	2.59	$3,742	22	2.36	$3,505	0.33	-$2,355	173
HCE 3%	80,000	3.46	$5,772	16	3.14	$5,535	0.44	-$1,971	130
HCE 3%	100,000	4.32	$7,802	13	3.93	$7,566	0.55	-$1,587	104
HCE 3%	120,000	5.19	$9,833	11	4.71	$9,596	0.66	-$1,204	86
HCE 3%	140,000	6.05	$11,863	9	5.50	$11,626	0.77	-$820	74
HCE 3%	160,000	6.91	$13,893	8	6.28	$13,657	0.88	-$437	65
HCE 3%	180,000	7.78	$15,924	7	7.07	$15,687	0.98	-$53	58
HCE 7%	60,000	2.38	$3,160	22	2.28	$3,059	0.31	-$2,337	173
HCE 7%	80,000	3.17	$4,978	16	3.04	$4,877	0.41	-$1,993	130
HCE 7%	100,000	3.96	$6,796	13	3.80	$6,695	0.51	-$1,650	104
HCE 7%	120,000	4.76	$8,614	11	4.56	$8,512	0.61	-$1,307	86
HCE 7%	140,000	5.55	$10,431	9	5.32	$10,330	0.71	-$963	74
HCE 7%	160,000	6.34	$12,249	8	6.07	$12,148	0.82	-$620	65
HCE 7%	180,000	7.14	$14,067	7	6.83	$13,966	0.92	-$276	58

Table 77. Carrier and Societal BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial LDW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0%)
LCE 3%	60,000	5.96	5.62	5	5.17	$2,808	2.20	$1,063	26
LCE 3%	80,000	7.95	7.49	7	6.89	$3,968	2.94	$1,712	19
LCE 3%	100,000	9.94	9.36	9	8.61	$5,129	3.67	$2,361	16
LCE 3%	120,000	11.93	11.23	10	10.33	$6,289	4.40	$3,010	13
LCE 3%	140,000	13.92	13.11	12	12.05	$7,450	5.14	$3,659	11
LCE 3%	160,000	15.90	14.98	14	13.77	$8,611	5.87	$4,308	10
LCE 3%	180,000	17.89	16.85	16	15.50	$9,771	6.61	$4,957	9
LCE 7%	60,000	5.21	$2,519	10	5.02	2496	2.07	$899	26
LCE 7%	80,000	6.95	$3,558	8	6.69	3535	2.75	$1,480	19
LCE 7%	100,000	8.68	$4,597	6	8.36	4574	3.44	$2,062	16
LCE 7%	120,000	10.42	$5,636	5	10.03	5613	4.13	$2,643	13
LCE 7%	140,000	12.16	$6,675	4	11.70	6652	4.82	$3,224	11
LCE 7%	160,000	13.89	$7,714	4	13.37	7691	5.51	$3,805	10
LCE 7%	180,000	15.63	$8,753	3	15.05	8730	6.20	$4,386	9
ACE 3%	60,000	4.65	$2,734	12	4.27	$2,666	1.81	$869	32
ACE 3%	80,000	6.21	$3,894	9	5.69	$3,827	2.41	$1,518	24
ACE 3%	100,000	7.76	$5,055	7	7.11	$4,987	3.01	$2,167	19
ACE 3%	120,000	9.31	$6,215	6	8.54	$6,148	3.61	$2,816	16
ACE 3%	140,000	10.86	$7,376	5	9.96	$7,308	4.21	$3,465	14
ACE 3%	160,000	12.41	$8,537	5	11.38	$8,469	4.81	$4,114	12
ACE 3%	180,000	13.96	$9,697	4	12.81	$9,630	5.42	$4,763	11
ACE 7%	60,000	4.31	$2,393	12	4.14	$2,666	1.69	$712	32
ACE 7%	80,000	5.74	$3,432	9	5.52	$3,827	2.25	$1,294	24
ACE 7%	100,000	7.18	$4,472	7	6.90	$4,987	2.82	$1,875	19
ACE 7%	120,000	8.61	$5,511	6	8.28	$6,148	3.38	$2,456	16
ACE 7%	140,000	10.05	$6,550	5	9.66	$7,308	3.95	$3,037	14
ACE 7%	160,000	11.48	$7,589	5	11.04	$8,469	4.51	$3,618	12
ACE 7%	180,000	12.92	$8,628	4	12.42	$9,630	5.07	$4,199	11
HCE 3%	60,000	3.97	$2,606	14	3.64	$2,524	1.53	$675	37
HCE 3%	80,000	5.30	$3,766	11	4.85	$3,685	2.04	$1,324	28
HCE 3%	100,000	6.62	$4,927	8	6.06	$4,846	2.55	$1,973	22
HCE 3%	120,000	7.95	$6,087	7	7.27	$6,006	3.06	$2,622	19
HCE 3%	140,000	9.27	$7,248	6	8.49	$7,167	3.57	$3,271	16
HCE 3%	160,000	10.60	$8,409	5	9.70	$8,327	4.08	$3,920	14
HCE 3%	180,000	11.92	$9,569	5	10.91	$9,488	4.59	$4,569	12
HCE 7%	60,000	3.67	$2,268	14	3.53	$2,233	1.43	$526	37
HCE 7%	80,000	4.89	$3,307	11	4.70	$3,272	1.91	$1,107	28
HCE 7%	100,000	6.12	$4,346	8	5.88	$4,311	2.39	$1,688	22
HCE 7%	120,000	7.34	$5,385	7	7.05	$5,350	2.86	$2,269	19
HCE 7%	140,000	8.56	$6,424	6	8.23	$6,389	3.34	$2,850	16
HCE 7%	160,000	9.79	$7,463	5	9.40	$7,428	3.82	$3,431	14
HCE 7%	180,000	11.01	$8,502	5	10.58	$8,468	4.29	$4,012	12

Table 78. Carrier and Societal Extended Service (7 Years) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial LDW Costs.

Blank	Blank	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**BCR**	**NPV**	**Payback Period (0%)**	**BCR**	**NPV**	**BCR**	**NPV**	**Payback Period (0 %)**
LCE 3%	60,000	6.02	$4,078	11	6.64	$4,024	2.87	$1,726	27
LCE 3%	80,000	8.03	$5,657	8	8.86	$5,603	3.83	$2,609	20
LCE 3%	100,000	10.03	$7,236	6	11.07	$7,182	4.78	$3,492	16
LCE 3%	120,000	12.04	$8,815	5	13.29	$8,760	5.74	$4,375	14
LCE 3%	140,000	14.05	$10,393	5	15.50	$10,339	6.70	$5,258	12
LCE 3%	160,000	16.05	$11,972	4	17.72	$11,918	7.65	$6,141	10
LCE 3%	180,000	18.06	$13,551	4	19.93	$13,497	8.61	$7,024	9
LCE 7%	60,000	6.52	$3,469	11	6.29	3445	2.62	$1,417	27
LCE 7%	80,000	8.69	$4,834	8	8.38	4811	3.49	$2,181	20
LCE 7%	100,000	10.86	$6,200	6	10.48	6177	4.37	$2,945	16
LCE 7%	120,000	13.04	$7,566	5	12.57	7543	5.24	$3,708	14
LCE 7%	140,000	15.21	$8,932	5	14.67	8908	6.12	$4,472	12
LCE 7%	160,000	17.38	$10,297	4	16.76	10274	6.99	$5,236	10
LCE 7%	180,000	19.55	$11,663	4	18.86	11640	7.86	$6,000	9
ACE 3%	60,000	6.02	$3,950	13	5.54	$3,882	2.37	$1,532	33
ACE 3%	80,000	8.03	$5,529	10	7.39	$5,461	3.16	$2,415	25
ACE 3%	100,000	10.03	$7,108	8	9.24	$7,040	3.95	$3,298	20
ACE 3%	120,000	12.04	$8,686	6	11.09	$8,619	4.74	$4,181	16
ACE 3%	140,000	14.05	$10,265	6	12.94	$10,198	5.53	$5,064	14
ACE 3%	160,000	16.05	$11,844	5	14.78	$11,777	6.32	$5,947	12
ACE 3%	180,000	18.06	$13,423	4	16.63	$13,355	7.11	$6,830	11
ACE 7%	60,000	5.43	$3,343	13	5.23	$3,882	2.16	$1,230	33
ACE 7%	80,000	7.24	$4,709	10	6.98	$5,461	2.88	$1,994	25
ACE 7%	100,000	9.06	$6,075	8	8.72	$7,040	3.60	$2,758	20
ACE 7%	120,000	10.87	$7,440	6	10.47	$8,619	4.32	$3,522	16
ACE 7%	140,000	12.68	$8,806	6	12.21	$10,198	5.04	$4,285	14
ACE 7%	160,000	14.49	$10,172	5	13.95	$11,777	5.76	$5,049	12
ACE 7%	180,000	16.30	$11,538	4	15.70	$13,355	6.48	$5,813	11
HCE 3%	60,000	5.18	$3,822	15	4.76	$3,741	2.02	$1,338	39
HCE 3%	80,000	6.90	$5,401	11	6.34	$5,319	2.69	$2,221	29
HCE 3%	100,000	8.63	$6,980	9	7.93	$6,898	3.37	$3,104	23
HCE 3%	120,000	10.35	$8,558	7	9.51	$8,477	4.04	$3,986	19
HCE 3%	140,000	12.08	$10,137	6	11.10	$10,056	4.71	$4,869	17
HCE 3%	160,000	13.81	$11,716	6	12.68	$11,635	5.39	$5,752	14
HCE 3%	180,000	15.53	$13,295	5	14.27	$13,214	6.06	$6,635	13
HCE 7%	60,000	4.66	$3,218	15	4.48	$3,183	1.84	$1,043	39
HCE 7%	80,000	6.21	$4,583	11	5.97	$4,549	2.45	$1,807	29
HCE 7%	100,000	7.76	$5,949	9	7.47	$5,914	3.06	$2,571	23
HCE 7%	120,000	9.32	$7,315	7	8.96	$7,280	3.67	$3,335	19
HCE 7%	140,000	10.87	$8,681	6	10.46	$8,646	4.28	$4,098	17
HCE 7%	160,000	12.42	$10,046	6	11.95	$10,012	4.90	$4,862	14
HCE 7%	180,000	13.97	$11,412	5	13.44	$11,377	5.51	$5,626	13

Table 79. Carrier and Societal Extended Service (10 Years) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial FCW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	BCR	NPV	Payback Period (0%)	BCR	NPV	BCR	NPV	Payback Period (0 %)
LCE 3%	60,000	7.71	$5,772	12	8.46	$5,718	3.71	$2,650	29
LCE 3%	80,000	10.28	$7,934	9	11.28	$7,880	4.95	$3,859	22
LCE 3%	100,000	12.86	$10,096	7	14.10	$10,042	6.19	$5,068	18
LCE 3%	120,000	15.43	$12,258	6	16.91	$12,203	7.42	$6,277	15
LCE 3%	140,000	18.00	$14,419	5	19.73	$14,365	8.66	$7,485	13
LCE 3%	160,000	20.57	$16,581	4	22.55	$16,527	9.90	$8,694	11
LCE 3%	180,000	23.14	$18,743	4	25.37	$18,689	11.14	$9,903	10
LCE 7%	60,000	8.02	$4,674	12	7.75	4650	3.28	$2,074	29
LCE 7%	80,000	10.69	$6,454	9	10.33	6430	4.37	$3,070	22
LCE 7%	100,000	13.36	$8,233	7	12.91	8210	5.46	$4,065	18
LCE 7%	120,000	16.03	$10,013	6	15.49	9990	6.55	$5,061	15
LCE 7%	140,000	18.70	$11,793	5	18.08	11770	7.64	$6,056	13
LCE 7%	160,000	21.38	$13,573	4	20.66	13550	8.73	$7,051	11
LCE 7%	180,000	24.05	$15,353	4	23.24	15330	9.83	$8,047	10
ACE 3%	60,000	7.71	$5,644	14	7.14	$5,577	3.10	$2,456	35
ACE 3%	80,000	10.28	$7,806	10	9.52	$7,739	4.13	$3,665	26
ACE 3%	100,000	12.86	$9,968	8	11.90	$9,900	5.16	$4,873	21
ACE 3%	120,000	15.43	$12,130	7	14.28	$12,062	6.19	$6,082	17
ACE 3%	140,000	18.00	$14,291	6	16.66	$14,224	7.23	$7,291	15
ACE 3%	160,000	20.57	$16,453	5	19.04	$16,385	8.26	$8,500	13
ACE 3%	180,000	23.14	$18,615	5	21.42	$18,547	9.29	$9,709	12
ACE 7%	60,000	6.75	$4,548	14	6.51	$5,577	2.72	$1,888	35
ACE 7%	80,000	8.99	$6,328	10	8.68	$7,739	3.62	$2,883	26
ACE 7%	100,000	11.24	$8,108	8	10.85	$9,900	4.53	$3,878	21
ACE 7%	120,000	13.49	$9,888	7	13.02	$12,062	5.44	$4,874	17
ACE 7%	140,000	15.74	$11,668	6	15.19	$14,224	6.34	$5,869	15
ACE 7%	160,000	17.99	$13,448	5	17.35	$16,385	7.25	$6,864	13
ACE 7%	180,000	20.24	$15,228	5	19.52	$18,547	8.15	$7,860	12
HCE 3%	60,000	6.69	$5,516	16	6.18	$5,435	2.66	$2,261	40
HCE 3%	80,000	8.92	$7,678	12	8.23	$7,597	3.54	$3,470	30
HCE 3%	100,000	11.16	$9,840	10	10.29	$9,759	4.43	$4,679	24
HCE 3%	120,000	13.39	$12,001	8	12.35	$11,920	5.31	$5,888	20
HCE 3%	140,000	15.62	$14,163	7	14.41	$14,082	6.20	$7,097	17
HCE 3%	160,000	17.85	$16,325	6	16.47	$16,244	7.08	$8,306	15
HCE 3%	180,000	20.08	$18,487	5	18.53	$18,405	7.97	$9,515	13
HCE 7%	60,000	5.82	$4,423	16	5.61	$4,388	2.32	$1,701	40
HCE 7%	80,000	7.76	$6,202	12	7.48	$6,168	3.10	$2,696	30
HCE 7%	100,000	9.70	$7,982	10	9.35	$7,948	3.87	$3,691	24
HCE 7%	120,000	11.64	$9,762	8	11.22	$9,728	4.65	$4,687	20
HCE 7%	140,000	13.59	$11,542	7	13.09	$11,507	5.42	$5,682	17
HCE 7%	160,000	15.53	$13,322	6	14.96	$13,287	6.19	$6,678	15
HCE 7%	180,000	17.47	$15,102	5	16.83	$15,067	6.97	$7,673	13

Table 80. Carrier High Deductible ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial LDW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	3.25	$1,813	14	3.61	$1,759	2.20	$1,063	26
LCE 3%	80,000	4.34	$2,624	11	4.81	$2,570	2.94	$1,712	19
LCE 3%	100,000	5.42	$3,435	9	6.02	$3,381	3.67	$2,361	16
LCE 3%	120,000	6.51	$4,246	7	7.22	$4,192	4.40	$3,010	13
LCE 3%	140,000	7.59	$5,057	6	8.42	$5,003	5.14	$3,659	11
LCE 3%	160,000	8.67	$5,868	5	9.62	$5,814	5.87	$4,308	10
LCE 3%	180,000	9.76	$6,679	5	10.83	$6,625	6.61	$4,957	9
LCE 7%	60,000	3.64	$1,580	14	3.50	1557	2.07	$899	26
LCE 7%	80,000	4.85	$2,306	11	4.67	2283	2.75	$1,480	19
LCE 7%	100,000	6.07	$3,032	9	5.84	3009	3.44	$2,062	16
LCE 7%	120,000	7.28	$3,758	7	7.01	3735	4.13	$2,643	13
LCE 7%	140,000	8.49	$4,484	6	8.18	4461	4.82	$3,224	11
LCE 7%	160,000	9.71	$5,210	5	9.35	5187	5.51	$3,805	10
LCE 7%	180,000	10.92	$5,936	5	10.51	5913	6.20	$4,386	9
ACE 3%	60,000	3.25	$1,685	17	2.98	$1,617	1.81	$869	32
ACE 3%	80,000	4.34	$2,496	13	3.98	$2,428	2.41	$1,518	24
ACE 3%	100,000	5.42	$3,307	10	4.97	$3,239	3.01	$2,167	19
ACE 3%	120,000	6.51	$4,118	9	5.97	$4,050	3.61	$2,816	16
ACE 3%	140,000	7.59	$4,929	7	6.96	$4,861	4.21	$3,465	14
ACE 3%	160,000	8.67	$5,740	7	7.95	$5,672	4.81	$4,114	12
ACE 3%	180,000	9.76	$6,551	6	8.95	$6,483	5.42	$4,763	11
ACE 7%	60,000	3.01	$1,454	17	2.89	$1,617	1.69	$712	32
ACE 7%	80,000	4.01	$2,180	13	3.86	$2,428	2.25	$1,294	24
ACE 7%	100,000	5.02	$2,906	10	4.82	$3,239	2.82	$1,875	19
ACE 7%	120,000	6.02	$3,632	9	5.79	$4,050	3.38	$2,456	16
ACE 7%	140,000	7.02	$4,359	7	6.75	$4,861	3.95	$3,037	14
ACE 7%	160,000	8.02	$5,085	7	7.72	$5,672	4.51	$3,618	12
ACE 7%	180,000	9.03	$5,811	6	8.68	$6,483	5.07	$4,199	11
HCE 3%	60,000	2.78	$1,557	20	2.54	$1,476	1.53	$675	37
HCE 3%	80,000	3.70	$2,368	15	3.39	$2,287	2.04	$1,324	28
HCE 3%	100,000	4.63	$3,179	12	4.24	$3,098	2.55	$1,973	22
HCE 3%	120,000	5.55	$3,990	10	5.08	$3,908	3.06	$2,622	19
HCE 3%	140,000	6.48	$4,801	9	5.93	$4,719	3.57	$3,271	16
HCE 3%	160,000	7.41	$5,612	8	6.78	$5,530	4.08	$3,920	14
HCE 3%	180,000	8.33	$6,423	7	7.62	$6,341	4.59	$4,569	12
HCE 7%	60,000	2.56	$1,329	20	2.46	$1,294	1.43	$526	37
HCE 7%	80,000	3.42	$2,055	15	3.28	$2,020	1.91	$1,107	28
HCE 7%	100,000	4.27	$2,781	12	4.11	$2,746	2.39	$1,688	22
HCE 7%	120,000	5.13	$3,507	10	4.93	$3,472	2.86	$2,269	19
HCE 7%	140,000	5.98	$4,233	9	5.75	$4,198	3.34	$2,850	16
HCE 7%	160,000	6.84	$4,959	8	6.57	$4,924	3.82	$3,431	14
HCE 7%	180,000	7.69	$5,685	7	7.39	$5,650	4.29	$4,012	12

Table 81. Carrier Low Deductible ($5,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial LDW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	1.69	$642	28	1.87	$588	2.20	$1,063	26
LCE 3%	80,000	2.25	$1,062	21	2.50	$1,008	2.94	$1,712	19
LCE 3%	100,000	2.81	$1,483	17	3.12	$1,429	3.67	$2,361	16
LCE 3%	120,000	3.37	$1,903	14	3.74	$1,849	4.40	$3,010	13
LCE 3%	140,000	3.94	$2,324	12	4.37	$2,270	5.14	$3,659	11
LCE 3%	160,000	4.50	$2,744	10	4.99	$2,690	5.87	$4,308	10
LCE 3%	180,000	5.06	$3,165	9	5.61	$3,111	6.61	$4,957	9
LCE 7%	60,000	1.89	$531	28	1.82	508	2.07	$899	26
LCE 7%	80,000	2.52	$908	21	2.42	885	2.75	$1,480	19
LCE 7%	100,000	3.15	$1,284	17	3.03	1261	3.44	$2,062	16
LCE 7%	120,000	3.78	$1,661	14	3.63	1638	4.13	$2,643	13
LCE 7%	140,000	4.41	$2,037	12	4.24	2014	4.82	$3,224	11
LCE 7%	160,000	5.03	$2,414	10	4.85	2391	5.51	$3,805	10
LCE 7%	180,000	5.66	$2,790	9	5.45	2767	6.20	$4,386	9
ACE 3%	60,000	1.69	$514	33	1.55	$446	1.81	$869	32
ACE 3%	80,000	2.25	$934	25	2.06	$867	2.41	$1,518	24
ACE 3%	100,000	2.81	$1,355	20	2.58	$1,287	3.01	$2,167	19
ACE 3%	120,000	3.37	$1,775	17	3.09	$1,708	3.61	$2,816	16
ACE 3%	140,000	3.94	$2,196	14	3.61	$2,128	4.21	$3,465	14
ACE 3%	160,000	4.50	$2,616	13	4.13	$2,549	4.81	$4,114	12
ACE 3%	180,000	5.06	$3,037	11	4.64	$2,969	5.42	$4,763	11
ACE 7%	60,000	1.56	$406	33	1.50	$446	1.69	$712	32
ACE 7%	80,000	2.08	$782	25	2.00	$867	2.25	$1,294	24
ACE 7%	100,000	2.60	$1,159	20	2.50	$1,287	2.82	$1,875	19
ACE 7%	120,000	3.12	$1,535	17	3.00	$1,708	3.38	$2,456	16
ACE 7%	140,000	3.64	$1,912	14	3.50	$2,128	3.95	$3,037	14
ACE 7%	160,000	4.16	$2,288	13	4.00	$2,549	4.51	$3,618	12
ACE 7%	180,000	4.68	$2,665	11	4.50	$2,969	5.07	$4,199	11
HCE 3%	60,000	1.44	$386	39	1.32	$304	1.53	$675	37
HCE 3%	80,000	1.92	$806	29	1.76	$725	2.04	$1,324	28
HCE 3%	100,000	2.40	$1,227	23	2.20	$1,145	2.55	$1,973	22
HCE 3%	120,000	2.88	$1,647	20	2.64	$1,566	3.06	$2,622	19
HCE 3%	140,000	3.36	$2,068	17	3.08	$1,987	3.57	$3,271	16
HCE 3%	160,000	3.84	$2,488	15	3.51	$2,407	4.08	$3,920	14
HCE 3%	180,000	4.32	$2,909	13	3.95	$2,828	4.59	$4,569	12
HCE 7%	60,000	1.33	$280	39	1.28	$245	1.43	$526	37
HCE 7%	80,000	1.77	$657	29	1.70	$622	1.91	$1,107	28
HCE 7%	100,000	2.22	$1,033	23	2.13	$998	2.39	$1,688	22
HCE 7%	120,000	2.66	$1,410	20	2.56	$1,375	2.86	$2,269	19
HCE 7%	140,000	3.10	$1,786	17	2.98	$1,752	3.34	$2,850	16
HCE 7%	160,000	3.55	$2,163	15	3.41	$2,128	3.82	$3,431	14
HCE 7%	180,000	3.99	$2,539	13	3.83	$2,505	4.29	$4,012	12

Table 82. Carrier High-Value Cargo ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial LDW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	6.06	$3,915	8	6.73	$3,861	2.20	$1,063	26
LCE 3%	80,000	8.08	$5,427	6	8.97	$5,373	2.94	$1,712	19
LCE 3%	100,000	10.11	$6,939	5	11.21	$6,884	3.67	$2,361	16
LCE 3%	120,000	12.13	$8,450	4	13.46	$8,396	4.40	$3,010	13
LCE 3%	140,000	14.15	$9,962	3	15.70	$9,908	5.14	$3,659	11
LCE 3%	160,000	16.17	$11,474	3	17.94	$11,420	5.87	$4,308	10
LCE 3%	180,000	18.19	$12,986	3	20.18	$12,931	6.61	$4,957	9
LCE 7%	60,000	6.79	$3,462	8	6.53	3439	2.07	$899	26
LCE 7%	80,000	9.05	$4,815	6	8.71	4792	2.75	$1,480	19
LCE 7%	100,000	11.31	$6,169	5	10.89	6146	3.44	$2,062	16
LCE 7%	120,000	13.57	$7,522	4	13.07	7499	4.13	$2,643	13
LCE 7%	140,000	15.83	$8,876	3	15.24	8853	4.82	$3,224	11
LCE 7%	160,000	18.10	$10,229	3	17.42	10206	5.51	$3,805	10
LCE 7%	180,000	20.36	$11,583	3	19.60	11559	6.20	$4,386	9
ACE 3%	60,000	6.06	$3,787	9	5.56	$3,720	1.81	$869	32
ACE 3%	80,000	8.08	$5,299	7	7.41	$5,231	2.41	$1,518	24
ACE 3%	100,000	10.11	$6,811	6	9.27	$6,743	3.01	$2,167	19
ACE 3%	120,000	12.13	$8,322	5	11.12	$8,255	3.61	$2,816	16
ACE 3%	140,000	14.15	$9,834	4	12.97	$9,766	4.21	$3,465	14
ACE 3%	160,000	16.17	$11,346	3	14.83	$11,278	4.81	$4,114	12
ACE 3%	180,000	18.19	$12,857	3	16.68	$12,790	5.42	$4,763	11
ACE 7%	60,000	5.61	$3,336	9	5.39	$3,720	1.69	$712	32
ACE 7%	80,000	7.48	$4,690	7	7.19	$5,231	2.25	$1,294	24
ACE 7%	100,000	9.35	$6,043	6	8.99	$6,743	2.82	$1,875	19
ACE 7%	120,000	11.22	$7,397	5	10.79	$8,255	3.38	$2,456	16
ACE 7%	140,000	13.09	$8,750	4	12.59	$9,766	3.95	$3,037	14
ACE 7%	160,000	14.96	$10,104	3	14.38	$11,278	4.51	$3,618	12
ACE 7%	180,000	16.83	$11,457	3	16.18	$12,790	5.07	$4,199	11
HCE 3%	60,000	5.18	$3,659	11	4.74	$3,578	1.53	$675	37
HCE 3%	80,000	6.90	$5,171	8	6.32	$5,090	2.04	$1,324	28
HCE 3%	100,000	8.63	$6,682	7	7.90	$6,601	2.55	$1,973	22
HCE 3%	120,000	10.35	$8,194	5	9.47	$8,113	3.06	$2,622	19
HCE 3%	140,000	12.08	$9,706	5	11.05	$9,625	3.57	$3,271	16
HCE 3%	160,000	13.80	$11,218	4	12.63	$11,136	4.08	$3,920	14
HCE 3%	180,000	15.53	$12,729	4	14.21	$12,648	4.59	$4,569	12
HCE 7%	60,000	4.78	$3,211	11	4.59	$3,176	1.43	$526	37
HCE 7%	80,000	6.37	$4,564	8	6.12	$4,530	1.91	$1,107	28
HCE 7%	100,000	7.97	$5,918	7	7.65	$5,883	2.39	$1,688	22
HCE 7%	120,000	9.56	$7,271	5	9.19	$7,237	2.86	$2,269	19
HCE 7%	140,000	11.15	$8,625	5	10.72	$8,590	3.34	$2,850	16
HCE 7%	160,000	12.75	$9,978	4	12.25	$9,943	3.82	$3,431	14
HCE 7%	180,000	14.34	$11,332	4	13.78	$11,297	4.29	$4,012	12

Table 83. Carrier High-Value Cargo ($1,000,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial LDW Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	39.12	$28,642	1	43.41	$28,587	2.20	$1,063	26
LCE 3%	80,000	52.16	$38,396	1	57.88	$38,341	2.94	$1,712	19
LCE 3%	100,000	65.20	$48,149	1	72.35	$48,095	3.67	$2,361	16
LCE 3%	120,000	78.24	$57,903	1	86.82	$57,849	4.40	$3,010	13
LCE 3%	140,000	91.28	$67,657	1	101.29	$67,603	5.14	$3,659	11
LCE 3%	160,000	104.32	$77,411	0	115.76	$77,357	5.87	$4,308	10
LCE 3%	180,000	117.36	$87,165	0	130.23	$87,111	6.61	$4,957	9
LCE 7%	60,000	43.79	$25,599	1	42.15	25576	2.07	$899	26
LCE 7%	80,000	58.38	$34,332	1	56.20	34309	2.75	$1,480	19
LCE 7%	100,000	72.98	$43,065	1	70.25	43041	3.44	$2,062	16
LCE 7%	120,000	87.57	$51,797	1	84.30	51774	4.13	$2,643	13
LCE 7%	140,000	102.17	$60,530	1	98.35	60507	4.82	$3,224	11
LCE 7%	160,000	116.76	$69,262	0	112.40	69239	5.51	$3,805	10
LCE 7%	180,000	131.36	$77,995	0	126.45	77972	6.20	$4,386	9
ACE 3%	60,000	39.12	$28,514	1	35.88	$28,446	1.81	$869	32
ACE 3%	80,000	52.16	$38,267	1	47.84	$38,200	2.41	$1,518	24
ACE 3%	100,000	65.20	$48,021	1	59.80	$47,954	3.01	$2,167	19
ACE 3%	120,000	78.24	$57,775	1	71.75	$57,708	3.61	$2,816	16
ACE 3%	140,000	91.28	$67,529	1	83.71	$67,461	4.21	$3,465	14
ACE 3%	160,000	104.32	$77,283	1	95.67	$77,215	4.81	$4,114	12
ACE 3%	180,000	117.36	$87,037	0	107.63	$86,969	5.42	$4,763	11
ACE 7%	60,000	36.19	$25,474	1	34.80	$28,446	1.69	$712	32
ACE 7%	80,000	48.26	$34,207	1	46.41	$38,200	2.25	$1,294	24
ACE 7%	100,000	60.32	$42,939	1	58.01	$47,954	2.82	$1,875	19
ACE 7%	120,000	72.39	$51,672	1	69.61	$57,708	3.38	$2,456	16
ACE 7%	140,000	84.45	$60,404	1	81.21	$67,461	3.95	$3,037	14
ACE 7%	160,000	96.52	$69,137	1	92.81	$77,215	4.51	$3,618	12
ACE 7%	180,000	108.58	$77,870	0	104.41	$86,969	5.07	$4,199	11
HCE 3%	60,000	33.40	$28,385	2	30.57	$28,304	1.53	$675	37
HCE 3%	80,000	44.53	$38,139	1	40.76	$38,058	2.04	$1,324	28
HCE 3%	100,000	55.67	$47,893	1	50.94	$47,812	2.55	$1,973	22
HCE 3%	120,000	66.80	$57,647	1	61.13	$57,566	3.06	$2,622	19
HCE 3%	140,000	77.93	$67,401	1	71.32	$67,320	3.57	$3,271	16
HCE 3%	160,000	89.07	$77,155	1	81.51	$77,074	4.08	$3,920	14
HCE 3%	180,000	100.20	$86,909	1	91.70	$86,827	4.59	$4,569	12
HCE 7%	60,000	30.84	$25,348	2	29.63	$25,314	1.43	$526	37
HCE 7%	80,000	41.13	$34,081	1	39.51	$34,046	1.91	$1,107	28
HCE 7%	100,000	51.41	$42,814	1	49.39	$42,779	2.39	$1,688	22
HCE 7%	120,000	61.69	$51,546	1	59.26	$51,511	2.86	$2,269	19
HCE 7%	140,000	71.97	$60,279	1	69.14	$60,244	3.34	$2,850	16
HCE 7%	160,000	82.25	$69,011	1	79.02	$68,977	3.82	$3,431	14
HCE 7%	180,000	92.53	$77,744	1	88.90	$77,709	4.29	$4,012	12

Table 84. Carrier and Societal BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial RSC Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0%)
LCE 3%	60,000	5.63	$1,389	10	5.26	$1,367	2.00	$397	29
LCE 3%	80,000	7.51	$1,952	8	7.01	$1,930	2.66	$662	22
LCE 3%	100,000	9.39	$2,514	6	8.77	$2,493	3.33	$928	17
LCE 3%	120,000	11.27	$3,077	5	10.52	$3,056	3.99	$1,193	14
LCE 3%	140,000	13.15	$3,640	4	12.27	$3,619	4.66	$1,458	12
LCE 3%	160,000	15.03	$4,203	4	14.03	$4,182	5.32	$1,723	11
LCE 3%	180,000	16.90	$4,766	3	15.78	$4,744	5.99	$1,989	10
LCE 7%	60,000	5.31	$1,227	10	5.14	1218	1.89	$336	29
LCE 7%	80,000	7.08	$1,731	8	6.85	1721	2.52	$573	22
LCE 7%	100,000	8.85	$2,235	6	8.57	2225	3.15	$811	17
LCE 7%	120,000	10.63	$2,739	5	10.28	2729	3.78	$1,048	14
LCE 7%	140,000	12.40	$3,243	4	11.99	3233	4.41	$1,286	12
LCE 7%	160,000	14.17	$3,747	4	13.70	3737	5.04	$1,523	11
LCE 7%	180,000	15.94	$4,250	3	15.42	4241	5.68	$1,761	10
ACE 3%	60,000	3.95	$1,261	14	3.66	$1,227	1.34	$203	43
ACE 3%	80,000	5.26	$1,823	11	4.88	$1,790	1.79	$468	32
ACE 3%	100,000	6.58	$2,386	9	6.10	$2,352	2.24	$733	26
ACE 3%	120,000	7.89	$2,949	7	7.32	$2,915	2.68	$999	21
ACE 3%	140,000	9.21	$3,512	6	8.54	$3,478	3.13	$1,264	18
ACE 3%	160,000	10.53	$4,075	5	9.75	$4,041	3.58	$1,529	16
ACE 3%	180,000	11.84	$4,638	5	10.97	$4,604	4.03	$1,795	14
ACE 7%	60,000	3.69	$1,102	14	3.56	$1,227	1.26	$149	43
ACE 7%	80,000	4.92	$1,605	11	4.75	$1,790	1.69	$386	32
ACE 7%	100,000	6.14	$2,109	9	5.94	$2,352	2.11	$624	26
ACE 7%	120,000	7.37	$2,613	7	7.12	$2,915	2.53	$861	21
ACE 7%	140,000	8.60	$3,117	6	8.31	$3,478	2.95	$1,099	18
ACE 7%	160,000	9.83	$3,621	5	9.50	$4,041	3.37	$1,337	16
ACE 7%	180,000	11.06	$4,125	5	10.68	$4,604	3.79	$1,574	14
HCE 3%	60,000	3.04	$1,133	19	2.80	$1,085	1.01	$9	56
HCE 3%	80,000	4.05	$1,695	14	3.73	$1,648	1.35	$274	42
HCE 3%	100,000	5.06	$2,258	11	4.67	$2,211	1.69	$539	34
HCE 3%	120,000	6.08	$2,821	9	5.60	$2,774	2.02	$805	28
HCE 3%	140,000	7.09	$3,384	8	6.53	$3,336	2.36	$1,070	24
HCE 3%	160,000	8.10	$3,947	7	7.46	$3,899	2.70	$1,335	21
HCE 3%	180,000	9.11	$4,509	6	8.40	$4,462	3.03	$1,600	19
HCE 7%	60,000	2.82	$976	19	2.72	$956	0.95	-$38	56
HCE 7%	80,000	3.76	$1,480	14	3.63	$1,460	1.27	$200	42
HCE 7%	100,000	4.70	$1,984	11	4.53	$1,964	1.58	$437	34
HCE 7%	120,000	5.65	$2,488	9	5.44	$2,467	1.90	$675	28
HCE 7%	140,000	6.59	$2,992	8	6.35	$2,971	2.22	$912	24
HCE 7%	160,000	7.53	$3,496	7	7.25	$3,475	2.53	$1,150	21
HCE 7%	180,000	8.47	$3,999	6	8.16	$3,979	2.85	$1,387	19

Table 85. Carrier and Societal Extended Service (7 Years) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial RCS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	4.92	$1,959	12	6.39	$1,937	2.47	$645	32
LCE 3%	80,000	6.57	$2,724	9	8.51	$2,703	3.30	$1,006	24
LCE 3%	100,000	8.21	$3,490	7	10.64	$3,469	4.12	$1,367	19
LCE 3%	120,000	9.85	$4,256	6	12.77	$4,234	4.95	$1,728	16
LCE 3%	140,000	11.49	$5,021	5	14.90	$5,000	5.77	$2,089	14
LCE 3%	160,000	13.13	$5,787	4	17.03	$5,766	6.60	$2,450	12
LCE 3%	180,000	14.77	$6,552	4	19.16	$6,531	7.42	$2,811	11
LCE 7%	60,000	6.31	$1,672	12	6.12	1663	2.30	$530	32
LCE 7%	80,000	8.42	$2,334	9	8.17	2325	3.07	$842	24
LCE 7%	100,000	10.52	$2,997	7	10.21	2987	3.84	$1,154	19
LCE 7%	120,000	12.62	$3,659	6	12.25	3649	4.60	$1,466	16
LCE 7%	140,000	14.73	$4,321	5	14.29	4312	5.37	$1,778	14
LCE 7%	160,000	16.83	$4,984	4	16.33	4974	6.14	$2,091	12
LCE 7%	180,000	18.94	$5,646	4	18.37	5636	6.91	$2,403	11
ACE 3%	60,000	4.92	$1,830	16	4.59	$1,797	1.71	$451	46
ACE 3%	80,000	6.57	$2,596	12	6.12	$2,562	2.29	$812	34
ACE 3%	100,000	8.21	$3,362	10	7.65	$3,328	2.86	$1,173	28
ACE 3%	120,000	9.85	$4,127	8	9.18	$4,094	3.43	$1,534	23
ACE 3%	140,000	11.49	$4,893	7	10.71	$4,859	4.00	$1,895	20
ACE 3%	160,000	13.13	$5,659	6	12.24	$5,625	4.57	$2,255	17
ACE 3%	180,000	14.77	$6,424	5	13.77	$6,391	5.14	$2,616	15
ACE 7%	60,000	4.51	$1,547	16	4.37	$1,797	1.58	$343	46
ACE 7%	80,000	6.02	$2,209	12	5.83	$2,562	2.10	$655	34
ACE 7%	100,000	7.52	$2,871	10	7.28	$3,328	2.63	$967	28
ACE 7%	120,000	9.03	$3,534	8	8.74	$4,094	3.15	$1,279	23
ACE 7%	140,000	10.53	$4,196	7	10.19	$4,859	3.68	$1,591	20
ACE 7%	160,000	12.03	$4,858	6	11.65	$5,625	4.21	$1,904	17
ACE 7%	180,000	13.54	$5,520	5	13.11	$6,391	4.73	$2,216	15
HCE 3%	60,000	3.86	$1,702	20	3.58	$1,655	1.31	$257	60
HCE 3%	80,000	5.15	$2,468	15	4.77	$2,421	1.75	$618	45
HCE 3%	100,000	6.44	$3,234	12	5.96	$3,186	2.18	$979	36
HCE 3%	120,000	7.73	$3,999	10	7.16	$3,952	2.62	$1,339	30
HCE 3%	140,000	9.01	$4,765	9	8.35	$4,718	3.06	$1,700	26
HCE 3%	160,000	10.30	$5,531	8	9.54	$5,483	3.50	$2,061	22
HCE 3%	180,000	11.59	$6,296	7	10.73	$6,249	3.93	$2,422	20
HCE 7%	60,000	3.51	$1,421	20	3.39	$1,401	1.20	$156	60
HCE 7%	80,000	4.68	$2,083	15	4.52	$2,063	1.60	$468	45
HCE 7%	100,000	5.85	$2,746	12	5.65	$2,725	2.00	$780	36
HCE 7%	120,000	7.02	$3,408	10	6.78	$3,388	2.40	$1,092	30
HCE 7%	140,000	8.19	$4,070	9	7.91	$4,050	2.80	$1,405	26
HCE 7%	160,000	9.36	$4,733	8	9.04	$4,712	3.20	$1,717	22
HCE 7%	180,000	10.53	$5,395	7	10.17	$5,375	3.60	$2,029	20

Table 86. Carrier and Societal Extended Service (10 Years) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial RCS Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	6.04	$2,752	14	7.60	$2,731	3.02	$991	37
LCE 3%	80,000	8.06	$3,801	10	10.14	$3,779	4.02	$1,485	28
LCE 3%	100,000	10.07	$4,849	8	12.67	$4,828	5.03	$1,979	22
LCE 3%	120,000	12.08	$5,897	7	15.20	$5,876	6.03	$2,473	18
LCE 3%	140,000	14.10	$6,946	6	17.74	$6,924	7.04	$2,967	16
LCE 3%	160,000	16.11	$7,994	5	20.27	$7,973	8.04	$3,461	14
LCE 3%	180,000	18.13	$9,042	5	22.81	$9,021	9.05	$3,956	12
LCE 7%	60,000	7.35	$2,237	14	7.15	2227	2.75	$776	37
LCE 7%	80,000	9.80	$3,100	10	9.54	3091	3.66	$1,183	28
LCE 7%	100,000	12.25	$3,963	8	11.92	3954	4.58	$1,590	22
LCE 7%	120,000	14.70	$4,827	7	14.31	4817	5.49	$1,997	18
LCE 7%	140,000	17.15	$5,690	6	16.69	5680	6.41	$2,404	16
LCE 7%	160,000	19.60	$6,553	5	19.08	6543	7.32	$2,810	14
LCE 7%	180,000	22.05	$7,416	5	21.46	7406	8.24	$3,217	12
ACE 3%	60,000	6.04	$2,624	18	5.67	$2,591	2.16	$797	51
ACE 3%	80,000	8.06	$3,673	14	7.56	$3,639	2.88	$1,291	38
ACE 3%	100,000	10.07	$4,721	11	9.46	$4,687	3.60	$1,785	30
ACE 3%	120,000	12.08	$5,769	9	11.35	$5,735	4.32	$2,279	25
ACE 3%	140,000	14.10	$6,818	8	13.24	$6,784	5.04	$2,773	22
ACE 3%	160,000	16.11	$7,866	7	15.13	$7,832	5.76	$3,267	19
ACE 3%	180,000	18.13	$8,914	6	17.02	$8,880	6.49	$3,761	17
ACE 7%	60,000	5.42	$2,112	18	5.26	$2,591	1.93	$589	51
ACE 7%	80,000	7.23	$2,975	14	7.01	$3,639	2.58	$996	38
ACE 7%	100,000	9.03	$3,838	11	8.77	$4,687	3.22	$1,403	30
ACE 7%	120,000	10.84	$4,701	9	10.52	$5,735	3.87	$1,810	25
ACE 7%	140,000	12.64	$5,564	8	12.27	$6,784	4.51	$2,217	22
ACE 7%	160,000	14.45	$6,427	7	14.03	$7,832	5.16	$2,623	19
ACE 7%	180,000	16.26	$7,290	6	15.78	$8,880	5.80	$3,030	17
HCE 3%	60,000	4.85	$2,496	22	4.52	$2,449	1.68	$602	65
HCE 3%	80,000	6.47	$3,545	17	6.03	$3,497	2.25	$1,097	48
HCE 3%	100,000	8.08	$4,593	13	7.53	$4,546	2.81	$1,591	39
HCE 3%	120,000	9.70	$5,641	11	9.04	$5,594	3.37	$2,085	32
HCE 3%	140,000	11.31	$6,689	10	10.54	$6,642	3.93	$2,579	28
HCE 3%	160,000	12.93	$7,738	8	12.05	$7,690	4.49	$3,073	24
HCE 3%	180,000	14.55	$8,786	7	13.56	$8,739	5.05	$3,567	22
HCE 7%	60,000	4.29	$1,986	22	4.15	$1,966	1.49	$402	65
HCE 7%	80,000	5.72	$2,849	17	5.54	$2,829	1.99	$809	48
HCE 7%	100,000	7.15	$3,712	13	6.92	$3,692	2.49	$1,216	39
HCE 7%	120,000	8.58	$4,576	11	8.30	$4,555	2.98	$1,623	32
HCE 7%	140,000	10.01	$5,439	10	9.69	$5,418	3.48	$2,030	28
HCE 7%	160,000	11.44	$6,302	8	11.07	$6,282	3.98	$2,437	24
HCE 7%	180,000	12.88	$7,165	7	12.46	$7,145	4.47	$2,843	22

Table 87. Carrier High Deductible ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial RSC Costs.

Blank	Blank	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**B/C**	**VAN**	**Payback Period (0%)**	**B/C**	**VAN**	**B/C**	**VAN**	**Payback Period (0 %)**
LCE 3%	60,000	2.33	$699	17	3.11	$677	2.00	$397	29
LCE 3%	80,000	3.11	$1,032	13	4.15	$1,010	2.66	$662	22
LCE 3%	100,000	3.89	$1,364	10	5.18	$1,343	3.33	$928	17
LCE 3%	120,000	4.67	$1,697	9	6.22	$1,676	3.99	$1,193	14
LCE 3%	140,000	5.45	$2,030	7	7.26	$2,009	4.66	$1,458	12
LCE 3%	160,000	6.22	$2,363	6	8.30	$2,341	5.32	$1,723	11
LCE 3%	180,000	7.00	$2,696	6	9.33	$2,674	5.99	$1,989	10
LCE 7%	60,000	3.14	$609	17	3.04	600	1.89	$336	29
LCE 7%	80,000	4.19	$907	13	4.05	898	2.52	$573	22
LCE 7%	100,000	5.24	$1,205	10	5.06	1196	3.15	$811	17
LCE 7%	120,000	6.28	$1,503	9	6.08	1494	3.78	$1,048	14
LCE 7%	140,000	7.33	$1,801	7	7.09	1792	4.41	$1,286	12
LCE 7%	160,000	8.38	$2,099	6	8.10	2090	5.04	$1,523	11
LCE 7%	180,000	9.42	$2,397	6	9.12	2387	5.68	$1,761	10
ACE 3%	60,000	2.33	$571	24	2.16	$537	1.34	$203	43
ACE 3%	80,000	3.11	$903	18	2.88	$870	1.79	$468	32
ACE 3%	100,000	3.89	$1,236	15	3.61	$1,202	2.24	$733	26
ACE 3%	120,000	4.67	$1,569	12	4.33	$1,535	2.68	$999	21
ACE 3%	140,000	5.45	$1,902	10	5.05	$1,868	3.13	$1,264	18
ACE 3%	160,000	6.22	$2,235	9	5.77	$2,201	3.58	$1,529	16
ACE 3%	180,000	7.00	$2,567	8	6.49	$2,534	4.03	$1,795	14
ACE 7%	60,000	2.18	$484	24	2.11	$537	1.26	$149	43
ACE 7%	80,000	2.91	$782	18	2.81	$870	1.69	$386	32
ACE 7%	100,000	3.63	$1,080	15	3.51	$1,202	2.11	$624	26
ACE 7%	120,000	4.36	$1,378	12	4.21	$1,535	2.53	$861	21
ACE 7%	140,000	5.09	$1,676	10	4.91	$1,868	2.95	$1,099	18
ACE 7%	160,000	5.81	$1,974	9	5.62	$2,201	3.37	$1,337	16
ACE 7%	180,000	6.54	$2,272	8	6.32	$2,534	3.79	$1,574	14
HCE 3%	60,000	1.80	$443	32	1.66	$395	1.01	$9	56
HCE 3%	80,000	2.39	$775	24	2.21	$728	1.35	$274	42
HCE 3%	100,000	2.99	$1,108	19	2.76	$1,061	1.69	$539	34
HCE 3%	120,000	3.59	$1,441	16	3.31	$1,394	2.02	$805	28
HCE 3%	140,000	4.19	$1,774	14	3.86	$1,726	2.36	$1,070	24
HCE 3%	160,000	4.79	$2,107	12	4.41	$2,059	2.70	$1,335	21
HCE 3%	180,000	5.39	$2,439	11	4.97	$2,392	3.03	$1,600	19
HCE 7%	60,000	1.67	$358	32	1.61	$338	0.95	-$38	56
HCE 7%	80,000	2.23	$656	24	2.14	$636	1.27	$200	42
HCE 7%	100,000	2.78	$954	19	2.68	$934	1.58	$437	34
HCE 7%	120,000	3.34	$1,252	16	3.22	$1,232	1.90	$675	28
HCE 7%	140,000	3.89	$1,550	14	3.75	$1,530	2.22	$912	24
HCE 7%	160,000	4.45	$1,848	12	4.29	$1,828	2.53	$1,150	21
HCE 7%	180,000	5.01	$2,146	11	4.82	$2,126	2.85	$1,387	19

Table 88. Carrier Low Deductible ($5,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial RSC Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	VMT	B/C	VAN	Payback Period (0%)	B/C	VAN	B/C	VAN	Payback Period (0 %)
LCE 3%	60,000	1.64	$401	25	2.18	$379	2.00	$397	29
LCE 3%	80,000	2.18	$634	18	2.91	$613	2.66	$662	22
LCE 3%	100,000	2.73	$867	15	3.64	$846	3.33	$928	17
LCE 3%	120,000	3.27	$1,101	12	4.36	$1,079	3.99	$1,193	14
LCE 3%	140,000	3.82	$1,334	11	5.09	$1,313	4.66	$1,458	12
LCE 3%	160,000	4.37	$1,568	9	5.82	$1,546	5.32	$1,723	11
LCE 3%	180,000	4.91	$1,801	8	6.54	$1,780	5.99	$1,989	10
LCE 7%	60,000	2.20	$342	25	2.13	333	1.89	$336	29
LCE 7%	80,000	2.94	$551	18	2.84	542	2.52	$573	22
LCE 7%	100,000	3.67	$760	15	3.55	751	3.15	$811	17
LCE 7%	120,000	4.41	$969	12	4.26	960	3.78	$1,048	14
LCE 7%	140,000	5.14	$1,178	11	4.97	1169	4.41	$1,286	12
LCE 7%	160,000	5.88	$1,387	9	5.68	1378	5.04	$1,523	11
LCE 7%	180,000	6.61	$1,596	8	6.39	1586	5.68	$1,761	10
ACE 3%	60,000	1.64	$272	35	1.52	$239	1.34	$203	43
ACE 3%	80,000	2.18	$506	26	2.02	$472	1.79	$468	32
ACE 3%	100,000	2.73	$739	21	2.53	$705	2.24	$733	26
ACE 3%	120,000	3.27	$973	17	3.03	$939	2.68	$999	21
ACE 3%	140,000	3.82	$1,206	15	3.54	$1,172	3.13	$1,264	18
ACE 3%	160,000	4.37	$1,439	13	4.05	$1,406	3.58	$1,529	16
ACE 3%	180,000	4.91	$1,673	12	4.55	$1,639	4.03	$1,795	14
ACE 7%	60,000	1.53	$217	35	1.48	$239	1.26	$149	43
ACE 7%	80,000	2.04	$426	26	1.97	$472	1.69	$386	32
ACE 7%	100,000	2.55	$635	21	2.46	$705	2.11	$624	26
ACE 7%	120,000	3.06	$844	17	2.95	$939	2.53	$861	21
ACE 7%	140,000	3.57	$1,053	15	3.45	$1,172	2.95	$1,099	18
ACE 7%	160,000	4.08	$1,262	13	3.94	$1,406	3.37	$1,337	16
ACE 7%	180,000	4.59	$1,471	12	4.43	$1,639	3.79	$1,574	14
HCE 3%	60,000	1.26	$144	45	1.16	$97	1.01	$9	56
HCE 3%	80,000	1.68	$378	34	1.55	$330	1.35	$274	42
HCE 3%	100,000	2.10	$611	27	1.93	$564	1.69	$539	34
HCE 3%	120,000	2.52	$845	22	2.32	$797	2.02	$805	28
HCE 3%	140,000	2.94	$1,078	19	2.71	$1,031	2.36	$1,070	24
HCE 3%	160,000	3.36	$1,311	17	3.10	$1,264	2.70	$1,335	21
HCE 3%	180,000	3.78	$1,545	15	3.48	$1,497	3.03	$1,600	19
HCE 7%	60,000	1.17	$91	45	1.13	$71	0.95	-$38	56
HCE 7%	80,000	1.56	$300	34	1.50	$280	1.27	$200	42
HCE 7%	100,000	1.95	$509	27	1.88	$489	1.58	$437	34
HCE 7%	120,000	2.34	$718	22	2.26	$698	1.90	$675	28
HCE 7%	140,000	2.73	$927	19	2.63	$907	2.22	$912	24
HCE 7%	160,000	3.12	$1,136	17	3.01	$1,116	2.53	$1,150	21
HCE 7%	180,000	3.51	$1,345	15	3.38	$1,325	2.85	$1,387	19

Table 89. Carrier High-Value Cargo ($50,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial RSC Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**B/C**	**VAN**	**Payback Period (0%)**	**B/C**	**VAN**	**B/C**	**VAN**	**Payback Period (0 %)**
LCE 3%	60,000	4.49	$1,621	9	5.98	$1,599	2.00	$397	29
LCE 3%	80,000	5.99	$2,261	7	7.98	$2,240	2.66	$662	22
LCE 3%	100,000	7.48	$2,901	5	9.97	$2,880	3.33	$928	17
LCE 3%	120,000	8.98	$3,541	4	11.97	$3,520	3.99	$1,193	14
LCE 3%	140,000	10.48	$4,181	4	13.96	$4,160	4.66	$1,458	12
LCE 3%	160,000	11.97	$4,821	3	15.96	$4,800	5.32	$1,723	11
LCE 3%	180,000	13.47	$5,461	3	17.95	$5,440	5.99	$1,989	10
LCE 7%	60,000	6.04	$1,435	9	5.85	1425	1.89	$336	29
LCE 7%	80,000	8.06	$2,008	7	7.79	1998	2.52	$573	22
LCE 7%	100,000	10.07	$2,581	5	9.74	2571	3.15	$811	17
LCE 7%	120,000	12.09	$3,154	4	11.69	3144	3.78	$1,048	14
LCE 7%	140,000	14.10	$3,727	4	13.64	3718	4.41	$1,286	12
LCE 7%	160,000	16.11	$4,300	3	15.59	4291	5.04	$1,523	11
LCE 7%	180,000	18.13	$4,873	3	17.54	4864	5.68	$1,761	10
ACE 3%	60,000	4.49	$1,493	13	4.16	$1,459	1.34	$203	43
ACE 3%	80,000	5.99	$2,133	9	5.55	$2,099	1.79	$468	32
ACE 3%	100,000	7.48	$2,773	8	6.93	$2,739	2.24	$733	26
ACE 3%	120,000	8.98	$3,413	6	8.32	$3,379	2.68	$999	21
ACE 3%	140,000	10.48	$4,053	5	9.71	$4,019	3.13	$1,264	18
ACE 3%	160,000	11.97	$4,693	5	11.09	$4,659	3.58	$1,529	16
ACE 3%	180,000	13.47	$5,333	4	12.48	$5,300	4.03	$1,795	14
ACE 7%	60,000	4.19	$1,309	13	4.05	$1,459	1.26	$149	43
ACE 7%	80,000	5.59	$1,882	9	5.40	$2,099	1.69	$386	32
ACE 7%	100,000	6.99	$2,455	8	6.75	$2,739	2.11	$624	26
ACE 7%	120,000	8.39	$3,029	6	8.10	$3,379	2.53	$861	21
ACE 7%	140,000	9.78	$3,602	5	9.45	$4,019	2.95	$1,099	18
ACE 7%	160,000	11.18	$4,175	5	10.80	$4,659	3.37	$1,337	16
ACE 7%	180,000	12.58	$4,748	4	12.15	$5,300	3.79	$1,574	14
HCE 3%	60,000	3.45	$1,365	16	3.18	$1,317	1.01	$9	56
HCE 3%	80,000	4.61	$2,005	12	4.24	$1,957	1.35	$274	42
HCE 3%	100,000	5.76	$2,645	10	5.31	$2,597	1.69	$539	34
HCE 3%	120,000	6.91	$3,285	8	6.37	$3,238	2.02	$805	28
HCE 3%	140,000	8.06	$3,925	7	7.43	$3,878	2.36	$1,070	24
HCE 3%	160,000	9.21	$4,565	6	8.49	$4,518	2.70	$1,335	21
HCE 3%	180,000	10.36	$5,205	5	9.55	$5,158	3.03	$1,600	19
HCE 7%	60,000	3.21	$1,184	16	3.09	$1,164	0.95	-$38	56
HCE 7%	80,000	4.28	$1,757	12	4.12	$1,737	1.27	$200	42
HCE 7%	100,000	5.35	$2,330	10	5.16	$2,310	1.58	$437	34
HCE 7%	120,000	6.42	$2,903	8	6.19	$2,883	1.90	$675	28
HCE 7%	140,000	7.49	$3,476	7	7.22	$3,456	2.22	$912	24
HCE 7%	160,000	8.56	$4,049	6	8.25	$4,029	2.53	$1,150	21
HCE 7%	180,000	9.63	$4,622	5	9.28	$4,602	2.85	$1,387	19

Table 90. Carrier High-Value Cargo ($1,000,000) BCR, NPV, and Payback Periods for Varying VMTs, Discount Rates, and Initial ESC/RSC Costs.

		Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier Without Financing	Motor Carrier With Financing	Motor Carrier With Financing	Society	Society	Society
Rates	**VMT**	**B/C**	**VAN**	**Payback Period (0%)**	**B/C**	**VAN**	**B/C**	**VAN**	**Payback Period (0 %)**
LCE 3%	60,000	19.21	$7,917	2	25.60	$7,895	2.00	$397	29
LCE 3%	80,000	25.61	$10,655	2	34.13	$10,634	2.66	$662	22
LCE 3%	100,000	32.01	$13,394	1	42.67	$13,373	3.33	$928	17
LCE 3%	120,000	38.42	$16,133	1	51.20	$16,112	3.99	$1,193	14
LCE 3%	140,000	44.82	$18,872	1	59.73	$18,850	4.66	$1,458	12
LCE 3%	160,000	51.22	$21,610	1	68.26	$21,589	5.32	$1,723	11
LCE 3%	180,000	57.62	$24,349	1	76.80	$24,328	5.99	$1,989	10
LCE 7%	60,000	25.85	$7,071	2	25.01	7062	1.89	$336	29
LCE 7%	80,000	34.47	$9,523	2	33.34	9514	2.52	$573	22
LCE 7%	100,000	43.09	$11,975	1	41.68	11966	3.15	$811	17
LCE 7%	120,000	51.71	$14,427	1	50.02	14418	3.78	$1,048	14
LCE 7%	140,000	60.33	$16,879	1	58.35	16870	4.41	$1,286	12
LCE 7%	160,000	68.94	$19,331	1	66.69	19322	5.04	$1,523	11
LCE 7%	180,000	77.56	$21,783	1	75.03	21774	5.68	$1,761	10
ACE 3%	60,000	19.21	$7,788	3	17.80	$7,755	1.34	$203	43
ACE 3%	80,000	25.61	$10,527	2	23.73	$10,493	1.79	$468	32
ACE 3%	100,000	32.01	$13,266	2	29.67	$13,232	2.24	$733	26
ACE 3%	120,000	38.42	$16,005	1	35.60	$15,971	2.68	$999	21
ACE 3%	140,000	44.82	$18,743	1	41.54	$18,710	3.13	$1,264	18
ACE 3%	160,000	51.22	$21,482	1	47.47	$21,448	3.58	$1,529	16
ACE 3%	180,000	57.62	$24,221	1	53.40	$24,187	4.03	$1,795	14
ACE 7%	60,000	17.94	$6,946	3	17.33	$7,755	1.26	$149	43
ACE 7%	80,000	23.92	$9,398	2	23.11	$10,493	1.69	$386	32
ACE 7%	100,000	29.90	$11,850	2	28.88	$13,232	2.11	$624	26
ACE 7%	120,000	35.88	$14,302	1	34.66	$15,971	2.53	$861	21
ACE 7%	140,000	41.86	$16,754	1	40.43	$18,710	2.95	$1,099	18
ACE 7%	160,000	47.84	$19,206	1	46.21	$21,448	3.37	$1,337	16
ACE 7%	180,000	53.82	$21,658	1	51.99	$24,187	3.79	$1,574	14
HCE 3%	60,000	14.78	$7,660	4	13.62	$7,613	1.01	$9	56
HCE 3%	80,000	19.71	$10,399	3	18.16	$10,352	1.35	$274	42
HCE 3%	100,000	24.64	$13,138	2	22.70	$13,091	1.69	$539	34
HCE 3%	120,000	29.56	$15,877	2	27.24	$15,829	2.02	$805	28
HCE 3%	140,000	34.49	$18,615	2	31.78	$18,568	2.36	$1,070	24
HCE 3%	160,000	39.42	$21,354	1	36.32	$21,307	2.70	$1,335	21
HCE 3%	180,000	44.34	$24,093	1	40.86	$24,046	3.03	$1,600	19
HCE 7%	60,000	13.74	$6,820	4	13.24	$6,800	0.95	-$38	56
HCE 7%	80,000	18.31	$9,272	3	17.65	$9,252	1.27	$200	42
HCE 7%	100,000	22.89	$11,724	2	22.06	$11,704	1.58	$437	34
HCE 7%	120,000	27.47	$14,176	2	26.47	$14,156	1.90	$675	28
HCE 7%	140,000	32.05	$16,628	2	30.88	$16,608	2.22	$912	24
HCE 7%	160,000	36.63	$19,080	1	35.29	$19,060	2.53	$1,150	21
HCE 7%	180,000	41.21	$21,532	1	39.71	$21,512	2.85	$1,387	19

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