Federal Motor Carrier Safety Administration's Advanced System Utilizing a Data Acquisition System on Highways (FAST DASH) Safety Technology Evaluation Project #1: Blindspot Warning

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

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FOREWORD

The mission of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce crashes, injuries, and fatalities involving large trucks and buses. FMCSA believes that the development, evaluation, and deployment of advanced safety technologies will be key to realizing this objective. Currently, there are numerous safety systems in development that have the potential to significantly reduce crashes on our nation's roadways. For a variety of reasons, however, including lack of supporting tests and evaluations, the potential benefits that these systems may provide in reducing crashes may never be realized.

A key focus of FMCSA is to provide leadership in the testing and evaluation of promising technologies so that these technologies can be implemented more rapidly and their potential benefits realized. Moving promising safety technologies from the design stage to the implementation and deployment stages is expected to lead to a reduction in large-truck crashes and their associated injuries and fatalities. The objective of FMCSA's Advanced System Testing utilizing a Data Acquisition System on the Highways (FAST DASH) program is to perform independent evaluations of promising safety technologies aimed at commercial vehicle operations.

NOTICE

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16. Abstract

The purpose of the Federal Motor Carrier Safety Administration's (FMCSA's) Advanced System Testing utilizing a Data Acquisition System on the Highways (FAST DASH) program is to conduct an efficient and independent evaluation of promising safety technologies aimed at improving commercial motor vehicle (CMV) operations. The CMV safety technology evaluated in this study was a blindspot object detection and warning system (BSW), which uses an array of infrared laser beams to create three-dimensional (3D) detection zones on either side of a CMV. The system alerts the driver of objects in the blindspots via activation of amber light-emitting diodes (LEDs) mounted on the side-view mirrors. This particular technology type was selected because it can address the leading heavy truck pre-crash scenario that an independent analysis by Volpe National Transportation Systems Center identified ("Changing lanes/Same direction"), and there is limited documentation of BSW system effectiveness for CMVs in industry literature. Results from the controlled tests and the field study indicate that the subject BSW system provides good coverage and helps to identify objects in the blindspot zones of CMVs. These blindspot zones pose a particular challenge to CMV drivers, especially on the passenger-side of the vehicle. System testing in controlled experiments on a test track showed that the system performed well at correctly detecting vehicles inside the detection zones and correctly ignoring vehicles outside the detection zones. During the field study, participating drivers indicated an overall user acceptance for the system. A safety benefit analysis was performed, using safety-critical events (SCEs) as a measure of risk, and results indicate practically significant improvements with a strong positive statistical trend for safety benefits.

17. Key Words **Commercial motor vehicle, commercial safety technology, blindspot warning, independent evaluation**		18. Distribution Statement **No restrictions**	
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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		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME	1000 L shall be shown in m^3	
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		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/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	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		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		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/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force & Pressure Or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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ABBREVIATIONS AND ACRONYMS

Acronym	Definition
3D	Three-dimensional
AI	analyst-identified
ANSUR	anthropometric survey
ATA	after task award
C/VIS	camera/video imaging system
CAN	controller area network
CDL	commercial driver’s license
CI	critical incident
CMV	commercial motor vehicle
COTR	Contracting Officer’s Technical Representative
CTD	Center for Technology Development
CUT	combination unit truck
CV	commercial vehicle
CVO	commercial vehicle operations
DAS	data acquisition system
DV	dependent variable
FAST DASH	FMCSA’s Advanced System Testing utilizing a Data Acquisition System on Highways
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operations test
FOV	field of view
GPS	global positioning system
IRB	Institutional Review Board
IV	independent variable
IVBSS	Integrated Vehicle-based Safety Systems

Acronym	Definition
LA	longitudinal acceleration
LD	lane deviation
LED	light-emitting diode
MATLAB	matrix laboratory
OEM	original equipment manufacturer
PI	principal investigator
PM	project manager
PRA	Paperwork Reduction Act
ROI	return on investment
S	swerve
SCE	safety-critical event
SD	standard deviation
SE	standard error
SOW	statement of work
TTC	time-to-collision
VMT	vehicle miles traveled
VNTSC	Volpe National Transportation Systems Center
VTTI	Virginia Tech Transportation Institute

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EXECUTIVE SUMMARY

PURPOSE

The Federal Motor Carrier Safety Administration (FMCSA) provides leadership in evaluating promising safety technologies for commercial motor vehicles (CMVs) by identifying their in-service benefits in a naturalistic driving environment. By identifying, quantifying, and documenting safety benefits of promising technologies, FMCSA encourages the voluntary adoption of proven safety systems by motor carriers. FMCSA's Advanced System Testing utilizing a Data Acquisition System on the Highways (FAST DASH) program conducts efficient and independent evaluations of promising safety technologies aimed at commercial vehicle operations (CVO) to serve this goal. The FAST DASH program is tasked to complete at least three technology evaluations over 5 years. The current report details all tasks completed during the first FAST DASH technology evaluation.

TECHNOLOGY

A blindspot object detection and warning system (BSW) was selected as the candidate safety technology for the first FAST DASH evaluation. This technology uses sensors to monitor areas to either side of the truck and provides drivers with an alert when vehicles or objects are detected in their blindspots. This information, when used in conjunction with conventional mirrors, has the potential to help drivers make better decisions during lane changes and merges. In contrast to legacy BSW systems that typically use radar- or ultrasonic-based sensors, the BSW technology evaluated in this study uses an array of infrared laser beams to create a three-dimensional (3D) detection zone on both the driver- and passenger-sides of a CMV. A driver is alerted to vehicles in the blindspot area via the activation of amber light-emitting diodes (LEDs) mounted on the left and right side-view mirrors.

PROCESS

This study represents a comprehensive evaluation of the tested BSW system. The FAST DASH study process included the following steps:

- ***Controlled Performance Testing—***The research team performed preliminary "shake-down testing" of the technology in a control environment to exercise and assess the performance capabilities reported by the vendor (i.e., determine the operational envelope). Performance capabilities of initial interest included: the object detection region for the driver- and passenger-side adjacent lanes, the object detection sensitivity, and performance in select inclement weather conditions. Tests were performed in both quasi-static and dynamic scenarios at the research team's facility.
- ***Field Study—***A BSW system's actual effectiveness depends on its real-world implementation and drivers' use and acceptance. The intent of the field study was to implement the BSW system within a revenue-producing fleet and exercise the system on public roadways in order to gain an understanding of the system's potential safety

benefits, system performance under real-world conditions, unintended consequences from the use of the system, and drivers' impressions of the technology.

RATIONALE AND BACKGROUND

CMVs have large areas around their body that are obscured from the driver's direct and indirect vision. These areas are often referred to as a CMV's "No-Zones" as defined by FMCSA's "Share the Road Safely" Program.[(1)] These blindspots may hide other road users and objects (e.g., other motor vehicles, cyclists, and pedestrians) from a CMV driver's view, increasing the risk of conflicts and crashes that may occur during maneuvers such as lane changes and lane merges.

In 2010, Volpe National Transportation Systems Center (VTNSC) defined pre-crash scenarios and estimated the frequency of different heavy-vehicle crash types based on a sample of police-reported crashes from 2005–08 involving unimpaired drivers. For the Lane Change Pre-crash Scenario,[(2)] VNTSC estimated that there were 49,000 heavy-vehicle crashes involved (13 percent of the total 375,000 crashes studied),[(3)] making lane changes the largest component, by frequency, of all pre-crash scenarios considered in the VNTSC analysis.[1] In a similar analysis of 2004–08 crash data, the Insurance Institute of Highway Safety (IIHS) stated that 39,000 heavy truck crashes were relevant to today's blindspot detection systems and indicated that blindspot detection technology offers the greatest potential in mitigating the largest number of large-truck crashes (approximately 10 percent of the estimated 384,000 annual crashes involving large trucks reported during the study time period).[(4)]

To reduce the frequency of these conflicts and crashes resulting from reduced visibility, CMV manufacturers and/or fleets have developed a variety of safety systems that monitor, via sensors (e.g., laser, radar, camera vision, ultrasonic), these specific obscured areas to provide drivers with indications (i.e., visual and/or audible warnings) when an object is present in the blindspot area. Previous evaluations of these technologies have revealed a potential benefit to these BSW systems, as well as a need for increased sensor reliability during unfavorable (i.e., rainy, windy) weather conditions and improvements in sensor performance, for example, a larger field of view (FOV).

STUDY FINDINGS

The research team systematically tested the BSW system under various operational scenarios to understand its abilities and limitations. The summary of field study effectiveness observations is documented in Table 1 and Table 2.

[1] The USDOT considers the "comprehensive cost" associated with pre-crash scenarios in assessing societal and economic impacts of accidents which may provide a different ranking than those implied by occurrence frequency itself. Societal harms analysis results specifically for large trucks and buses have not yet been published; however, a summary for accidents involving all vehicle types within the context of vehicle-to-vehicle communications can be found on Table 3 in http://ntl.bts.gov/lib/38000/38600/38671/Najm_Pre-crashScenario.pdf.

Table 1. Summary of field study results for the BSW.

Characteristic Measured	Baseline Period	Intervention Period
Total number of safety-critical events (SCEs) observed	99	112
Total number of blindspot-warning-related SCEs observed	18	15
Total amount of validated driving data collected (miles)	283,235	439,404
Total SCE rate (per 10,000 vehicle miles traveled [VMT])	3.5	2.55
Blindspot-warning-related SCE rate (per 10,000 VMT)	0.64	0.34

Table 2. Summary of BSW system effectiveness observation from the field study.

Overall SCE Rate Comparison	Baseline Period SCE Rate	Reduction During Intervention Period	Percent SCE Reduction
Total SCEs (per 10,000 VMT)	3.50	0.95	27.1%
Blindspot-warning-related SCE rate (per 10,000 VMT)	0.64	0.30	46.9%
Non-parametric Wilcoxon Signed Rank Test Results Summary‡	**Baseline Period SCE Rate**	**Reduction During Intervention Period**	**Percent SCE Reduction**
Total SCE rate (per 10,000 VMT)	3.50	0.66*	18.9%
Blindspot-warning-related SCE rate (per 10,000 VMT)	0.64	0.37**	57.8%

*Mean SCE rate difference. p=0.0539.

**Mean SCE rate difference. p=0.0824.

‡Statistical analysis results from non-parametric Wilcoxon signed rank test are used throughout the report.

Controlled Performance Testing

Preliminary “shake-down testing” was performed in order to measure the BSW system’s operational envelope and performance in a controlled setting. This preliminary testing was performed in both quasi-static (i.e., the BSW-equipped vehicle remained stationary while targets were slowly operated around the equipped vehicle) and dynamic scenarios on the Virginia Smart Road. Results were supportive of vendor specifications, confirming that the BSW system provided comprehensive coverage on the sides of the tractor-trailer generally known as the “No-Zone” regions. Also, the BSW system addressed a large blindspot zone created by the drivers looking over the passenger side of the hood by adding an additional forward-looking sensor. Two areas were discovered where the system’s coverage could be further improved. The driver-side sensor unit left an area directly adjacent to the tractor uncovered for high-sitting, eye-height positions. This uncovered area was large enough to fit a motorcycle in three different positions, but not large enough to fit a small passenger vehicle. On both the driver- and passenger-sides, the BSW detection zones do not provide coverage for the rear two-thirds of the trailer for about half of the adjacent lanes (an area where the FOV for flat mirrors is limited). Some CMV drivers prefer to rely on flat mirrors to spot adjacent vehicles and to perceive their associated speeds rather than using their convex mirrors.

The BSW system’s ability to sense vehicles of varying sizes under varying environmental conditions was also tested. Results from the quasi-static testing showed that the subject BSW system performed well at accurately detecting light vehicles of various types and sizes (true positive detection performance), and performed well at accurately rejecting light vehicles of different types and sizes when they were not in the detection zone (true negative detection performance). During passing and merging testing on the Smart Road, the BSW system performed suitably in detecting light vehicles of different types and sizes under varying conditions (multiple vehicles present, rain, and varying light-vehicle approach scenarios). Rain spray from the equipped vehicle and small vehicle approach angles appeared to result in some false positives and false negatives, respectively.

Field Study

The effectiveness of the subject BSW system was investigated in a 20-vehicle field study under naturalistic driving scenarios. In this study, the safety benefits of the BSW system, its potential unintended consequences, driver acceptance of the technology, and the system's overall performance were evaluated. The research team collected approximately 722,639 miles (1,162,975 kilometers) of on-road data over approximately 11 months. This data was analyzed to evaluate the object detection performance and in-service safety benefits of the subject BSW system.

An evaluation of the BSW system's object detection performance was conducted by sampling a portion of data from each driver for each week of his or her intervention participation. This effort was conducted to assist in validating the accuracy of the BSW system and required the use of video and kinematic data. Trained reductionists identified 5 mi (approximately 8 km) of daytime driving per week for each driver, and 5 mi (approximately 8 km) of nighttime driving per week for each driver (if available). During each 5-mile section, 10 segments were randomly selected. For each segment, a snapshot of the video and the BSW system visual alert data were evaluated. Rates were calculated to evaluate the BSW system's ability to correctly detect all objects in the detection zone and correctly reject all objects outside of the detection zone. Results from these analyses found a 90.30 percent correct detection rate for the driver-side and a 92.03 percent correct detection rate for the passenger-side. The performance evaluation also showed that a correct rejection rate of 94.13 percent was found for the driver-side (5.87 percent false alarm rate), and a 94.89 percent correct rejection rate was found for the passenger-side (5.11 percent false alarm rate). The high correct rejection rates are indicative of a well-designed BSW system.

A second analysis was performed to investigate whether the operator's driving behavior, as measured by the rate of involvement in safety-critical events (SCEs), changed when the BSW system was introduced after the baseline period. One would hypothesize that an effective BSW system would improve drivers' lane change/merge behaviors and possibly improve their overall safety driving performance. Two analyses were performed using SCEs to evaluate the safety benefit of the subject BSW system. These analyses indicated that the BSW system may improve in-service driving safety for a fleet:

- First, all baseline period SCEs were compared to all intervention period SCEs using a non-parametric Wilcoxon Signed Rank test. In this test, overall SCE rate was reduced from 3.50 SCEs per 10,000 miles to 2.55 SCEs per 10,000 miles with a mean SCE rate difference of 0.66 SCEs per 10,000 miles between baseline and intervention periods (a p value of 0.0539).

- Second, SCEs were filtered to include only lane change/merge conflicts, again comparing baseline to intervention periods using a parametric paired t-test. In this test, overall SCE rate was reduced from 0.64 SCEs per 10,000 miles to 0.34 SCEs per 10,000 miles with a mean SCE rate difference of 0.37 SCEs per 10,000 miles between baseline and intervention periods (a *p* value of 0.0824).

An investigation of drivers' opinions on the BSW system's performance during normal driving conditions revealed that overall participants' performance expectations of the BSW system before its implementation were met during the 4 months that it was installed and functional on their vehicles. Their mean responses indicated that the system helped improve driving performance, helped to eliminate blindspots, was easy to use, and glare from the visual warnings was comfortable. In addition, six of the seven participants became comfortable using the BSW system to its full extent within the first month.

CONCLUSIONS

Results from both controlled performance testing and the field study indicate that the tested system provides good coverage in detecting objects in the blindspot areas around a CMV. The system performed well at correctly detecting vehicles inside the detection zones and correctly rejecting vehicles outside the detection zones during controlled track testing and the field study. Participants in the study responded positively to the implementation of the BSW system and indicated that it did yield positive safety benefits, overall.

Although the majority of findings were positive for the BSW system, some results showed opportunities for improved performance.

Further, a BSW system's perceived performance appears closely tied to its warning mechanism. Additional research on best methods to convey BSW messages to the driver would be beneficial.

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1. INTRODUCTION

1.1 BACKGROUND AND RESEARCH OBJECTIVES

The safety objective of the Federal Motor Carrier Safety Administration (FMCSA) "… is to reduce crashes, injuries and fatalities involving large trucks and buses."(5) Developing, evaluating, and deploying advanced safety technologies assists in achieving this objective.

There are numerous safety systems in development that have the potential to significantly reduce crashes on our Nation's roadways at any given time; however, the potential benefits that these systems might provide in reducing crashes may never be realized. While the reasons for this vary, one factor is the lack of supporting tests and evaluations to help the industry understand and communicate the true in-service benefits of the underlying systems. FMCSA envisions that promising commercial motor vehicle (CMV) safety technologies that support the expanding role of the trucking industry to safely, securely, and efficiently transport the Nation's goods and products can be identified and deployed through cooperation with the trucking industry. One way to save lives and reduce the number of injuries resulting from large-truck and bus crashes is to implement vehicle safety technologies such as passive and active collision mitigation and active driver behavior monitoring. Data that assesses the effectiveness of these systems are necessary to promote their use in the trucking industry.

A key focus of FMCSA is to provide leadership in the testing and evaluation of promising technologies so that their independently identified performance information can be made available to CMV stakeholders, an activity which may encourage quicker and wider technology adoption by motor carriers. Moving promising safety technologies from the design stage to the implementation and deployment stages is expected to lead to a reduction in large-truck crashes and their associated injuries and fatalities. FMCSA's Advanced System Testing utilizing a Data Acquisition System on the Highways (FAST DASH) program is structured to perform efficient, independent evaluations of promising safety technologies aimed at commercial vehicle operations (CVO) to accomplish these objectives. The vision of this program is to provide technology insight to the commercial trucking industry in hopes of promoting the adoption into CVOs of effective and proven safety systems validated during in-service operations. The efficacy of these safety systems is investigated using the following high-level metrics:

- Crash reduction effectiveness (i.e., safety benefits).
- Unintended consequences (i.e., safety disadvantages).
- User acceptance (e.g., driver, safety manager subjective opinions).

Under a 5-year cooperative agreement between FMCSA and the Virginia Tech Transportation Institute (VTTI), the FAST DASH program is structured to complete three technology evaluations. The body of this report will focus on the first technology evaluation, which has been completed.

The commencement of the FAST DASH technology evaluation process begins with the solicitation for technology candidates to submit their intent to partner with VTTI in assessing their system. The research team developed and posted a sources-sought notice via a dedicated FAST DASH webpage for the purpose of soliciting proposals from safety technology vendors (Appendix A). A technology vendor statement of work (SOW) was made available on this webpage which provided details on the FAST DASH program and the requirements for proposal submission. In addition to posting the sources-sought notice, researchers created a list of potential technology vendors and contacted them via e-mail for the purpose of directing interest toward the webpage solicitation. A press release regarding this solicitation was created and sent to CVO media outlets and was posted on the research team's Web site. A total of 10 technology vendors submitted proposals for consideration, which included a total of 11 safety systems/technologies. These proposals were reviewed and the safety technologies were categorized by type, potential safety benefits, and ease of implementation.

All proposed technologies and the FAST DASH project plan were presented to the Contracting Officer's Technical Representative (COTR) and other FMCSA personnel for consideration. After a thorough review, a final candidate was selected by FMCSA. A blindspot object detection and warning system (BSW) was selected for evaluation (see Appendix B). This technology uses sensors to monitor areas on either side of the truck and provides drivers with an alert when vehicles/objects are in the blindspots. This information, along with conventional mirror coverage, has the potential to help drivers make better decisions during lane changes and merges.

According to the technology vendor, the subject BSW system provides a number of benefits. It has a simple driver interface implemented on the side-view mirrors with large zone for blindspot detection, and it is easy to use, reliable, and low-cost. This BSW system is a patented infrared technology that uses an array of 7–15 lasers to create a three-dimensional (3D) detection zone on both the driver- and passenger-sides of a CMV (see Figure 1, Figure 2, Figure 3, and Figure 4). A driver is alerted to the existence of objects (vehicles) in these blindspots via three amber light-emitting diodes (LEDs) mounted on both side-view mirrors. If an object is detected, the three LEDs associated with that zone (driver-side or passenger-side) will stay lit for the entire time the object remains in the zone plus 2 seconds. The system is powered by the vehicle's battery/power supply.

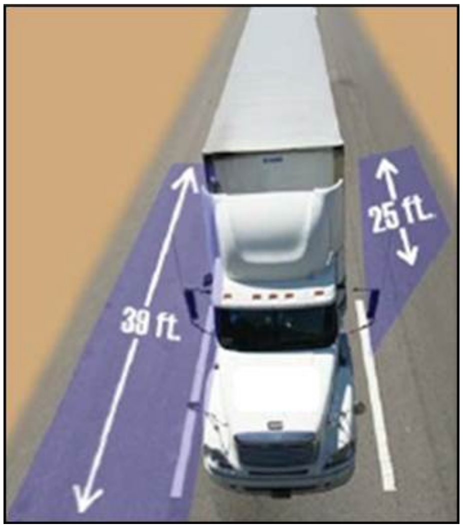

Figure 1. Diagram. Top-down view of tractor-trailer with BSW detection zones on passenger- and driver-sides.

Figure 2. Image. BSW sensor housing installed on tractor-trailer.

Figure 3. Image. Close-up of BSW sensor housing.

Figure 4. Image. BSW visual warning mounted on CMV flat mirror.

1.2 PROBLEM SCOPE

Large trucks, because of their size and design, have extensive areas around their bodies that are obscured from the driver's direct and indirect vision. These blindspot areas (Figure 5) have the potential to hide other road users (e.g., motor vehicles, cyclists, and pedestrians) from the driver's field of view (FOV), contributing to safety conflicts and crashes during maneuvers such as lane changes and merges. In fact, lane changes and merges are considered some of the riskiest maneuvers that a driver can perform on the highway, due to the high demand on the driver's attention and vision. (6)(7)

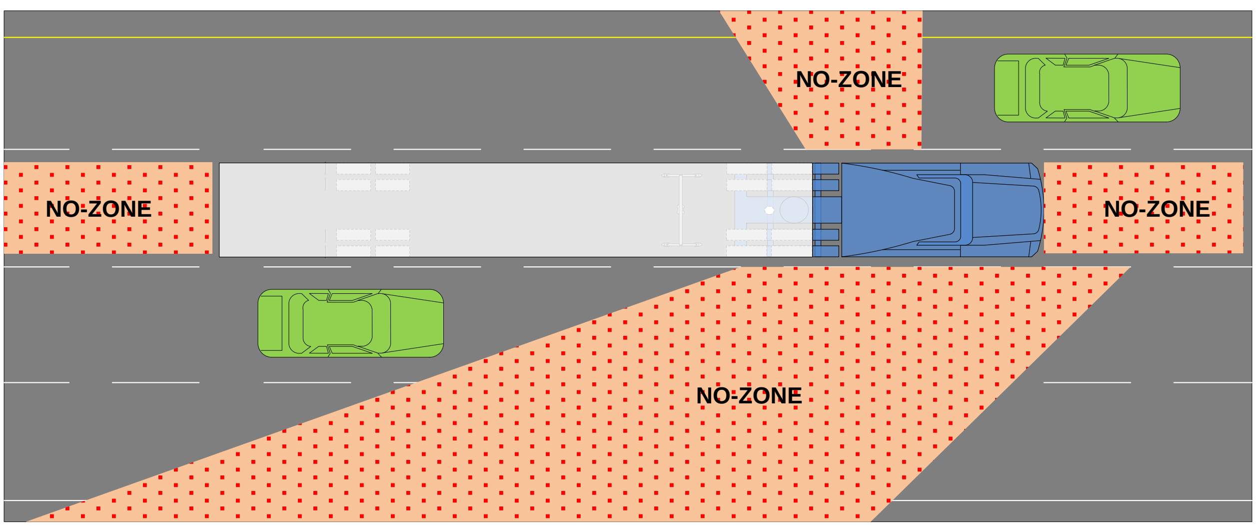

Figure 5. Diagram. Tractor-trailer blindspots adapted from the FMCSA NO-ZONE campaign.

In 2010, the Volpe National Transportation Systems Center (VNTSC) estimated the frequency of different heavy-vehicle crash types based on a sample of police-reported crashes from 2005–08 involving unimpaired drivers. For the Lane Change Pre-crash Scenario(8) VNTSC estimates that there were 49,000 (13 percent of 375,000) heavy-vehicle crashes.[9] In a similar analysis of 2004–08 crash data, the Insurance Institute of Highway Safety stated that 39,000 heavy truck crashes were relevant to today's blindspot detection systems and indicated that blindspot detection technology offers the greatest potential in mitigating the largest number of large-truck crashes (approximately 10 percent, of the estimated 384,000 annual crashes involving large trucks reported during the study time period).[10]

To mitigate these blindspot conflicts and crashes, vehicle manufacturers and/or fleets have incorporated safety systems that monitor, via sensors (e.g., infrared laser, radar, camera vision, ultrasonic), these specific obscured areas to provide drivers with visual and/or audible warnings when a vehicle is present in their blindspot areas. One of the earliest tests of BSW technologies[11] (with radar and ultrasonic sensors) found that all of the technologies at the time needed further development before the full potential for preventing crashes could be realized. Although the drivers involved with this early evaluation found value in using the BSW systems, the researchers suggested increases in sensor reliability during unfavorable weather conditions and improvements in sensor performance (i.e., larger FOV). As the technologies evolved, more robust systems were developed but some flaws remained. More recent evaluations[12,13] of BSW technologies found the strengths and weaknesses presented in Table 3. It is important to note that the only evaluation of infrared laser BSW technology was focused on detection of pedestrians around transit buses.[14] Also, a scan of relevant literature revealed that the side-object detection performance of infrared laser-based BSW technology under normal highway driving with large trucks is lacking.

Table 3. Reported strengths and weaknesses of BSW technologies.

	Ultrasonic	Radar	Infrared Laser	Camera Vision
Strengths	• Accuracy in detecting a cylindrical or perpendicular surfaces.	• Object distance and angle can be determined with high accuracy. • Not affected by environmental factors such as rain, fog, poor visibility, dust, or snow.	• Object distance and angle can be determined with high accuracy.	• Object motion can be determined with accuracy.
Weaknesses	• Performance affected by temperature, atmospheric pressure, humidity, wind, and rain. • Lower accuracy in detecting objects with angled surfaces or corners.	• False alarms from the detection of stationary objects.	• Performance affected by fog and snow.	• Performance affected by environmental factors such as fog and snow.

Sources: All strengths and weaknesses were taken from Najm, W.G., Koopman, J., Smith, J.D., and Brewer, J., (2010) with the exception of radar weaknesses, which were taken from Jermakian, J. S. (2012).

The reason for choosing the BSW system for the first FAST DASH technology evaluation was twofold. First, crash data indicates that BSW systems have great potential to reduce heavy-truck lane-change crashes. Second, the previously reported limitations of traditional BSW technologies (e.g., ultrasonic and radar) have negatively impacted the industry's adoption of the technology. For these two reasons, it was important to evaluate this newer side-object detection technology (which utilizes infrared lasers) by examining the technology's performance within a revenue-producing trucking fleet and exercising the system on public roadways. The ultimate goal of the evaluation is to help the relevant population gain an understanding of the system's potential safety benefits, system performance under real-world conditions, unintended consequences from use of the system, and drivers' impressions of the technology.

1.3 ORGANIZATION OF THE CURRENT REPORT

The current report details all tasks completed during the first FAST DASH technology evaluation. These tasks are briefly described in this section so that the reader can understand the logical progression of events that took place.

1.3.1 Preliminary Performance Testing

As mentioned, the BSW system uses an array of infrared lasers on both the driver- and passenger-sides of a CMV and presents a visual warning to the driver via amber LEDs positioned on the side-view mirrors. Preliminary testing of this technology was performed in both quasi-static (i.e., the BSW system-equipped vehicle remained stationary while targets were slowly moved around the equipped vehicle) and dynamic scenarios on the Virginia Smart Road. Results from preliminary testing will be presented in this section.

1.3.2 Field Study

A fleet was selected for participation in the FAST DASH field study early in the first evaluation. Primary factors that were considered during the selection process included the type of operation (e.g., long-haul), willingness to participate, and the availability of clear and complete fleet-owned data. A total of 20 CMVs were equipped with the research team's data acquisition system (DAS) and the BSW system. Data were collected over a period of approximately 11 months resulting in 722,639 mi (1,162,975 km) of analyzed data. All methods used to evaluate the BSW system, in addition to results found during the field study, will be discussed in this section.

1.3.3 Conclusions

Conclusions found across all methods of technology evaluation will be discussed in this section (i.e., quasi-static and dynamic preliminary performance testing, safety performance [safety-critical event (SCE) comparison], qualitative data, BSW system performance, and fleet-owned data analysis).

1.3.4 Recommendations

Based on the findings of this evaluation, the research team provides suggested improvements to the tested technology that could be applied to all BSW systems as well as a recommendation to further research effective warning mechanisms in this final section.

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2. CONTROLLED PERFORMANCE TESTING

Prior to conducting a field study to evaluate the BSW system, the research team performed preliminary "shake-down testing." The purpose of controlled testing was to exercise the performance capabilities expected from the system (i.e., determine the operational envelope), and to evaluate the interface capabilities of the BSW system with the research team's DAS. For example, performance capabilities of initial interest for preliminary testing included: object detection region determination for both the driver- and passenger-side adjacent lanes, object detection sensitivity identification, and performance degradation testing in select inclement weather conditions. It was recommended that the controlled testing be performed in both quasi-static and dynamic scenarios at the research team's facility.

2.1 QUASI-STATIC TESTING (ASPHALT PAD TESTING)

The main purpose of quasi-static testing was to evaluate the object detection regions and object detection accuracy of the BSW system in a controlled and safe environment. Quasi-static testing was split into these two efforts (i.e., object detection zone mapping and object detection performance).

2.1.1 Object Detection Zone Mapping

An initial effort was performed to map the detection zone of the BSW system using approaching light vehicles of different types. The detection zone maps were generated to make a direct comparison to the visual detection zone afforded by the experimental combination unit truck (CUT) mirrors for drivers of different statures/sitting-heights.

2.1.1.1 Method

Study Design

All testing was performed with trained researchers and engineers. Drivers representing both bookends of the sitting eye-height (low and high) spectrum were used during data collection. Based on anthropometric data pulled from the 1988 ANSUR database,[15] the research team selected a 5th percentile stature female driver approximately 5 ft (1.52 m) tall to represent the low-sitting eye-height position, and a 95th percentile stature male driver approximately 6 ft 2 inches (1.88 m) tall to represent the high-sitting eye-height position.

Apparatus

A sleeper-berth tractor with a 53 ft (16.15 m) box-van trailer was equipped with the BSW system and used during these tests (Figure 6, Figure 7, Figure 8, and Figure 9). This experimental CUT was positioned in the center of a six-lane asphalt pad located at the research team's facility. Two light vehicles and a motorcycle (experimental vehicles) were used as the primary objects for both driver visual detection and BSW detection (Figure 10). The dimensions of each of the experimental vehicles can be found in Table 2. The mid-sized sedan and motorcycle were used for evaluating the BSW system's sensitivity to vehicle width. The compact light vehicle (substantially lower to the ground than the mid-sized sedan) was used to evaluate the BSW system's sensitivity to vehicle height.

Figure 6. Image. Tractor and 53 ft (16.15 m) box-van trailer (experimental CUT) used for all preliminary tests.

Figure 7. Image. Driver-side BSW system's sensor position.

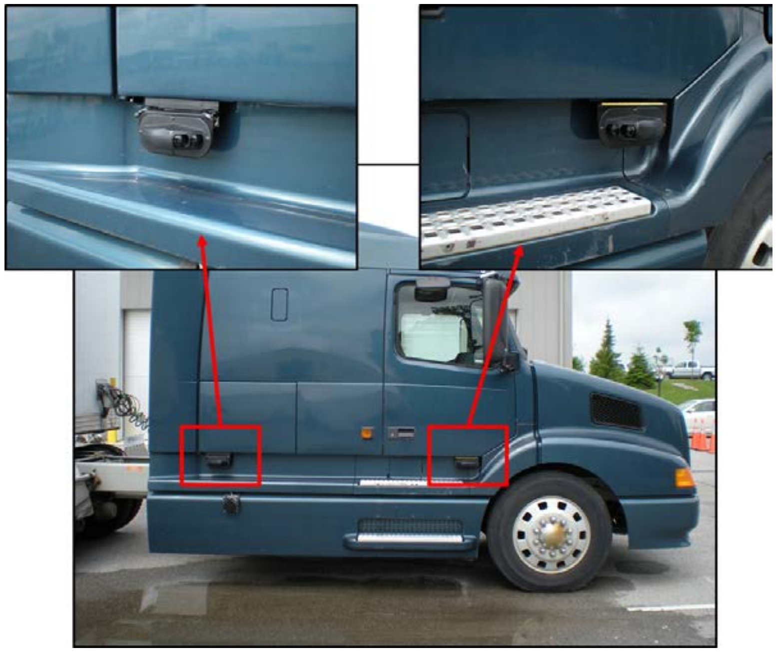

Figure 8. Image. Passenger-side BSW system's sensor positions.

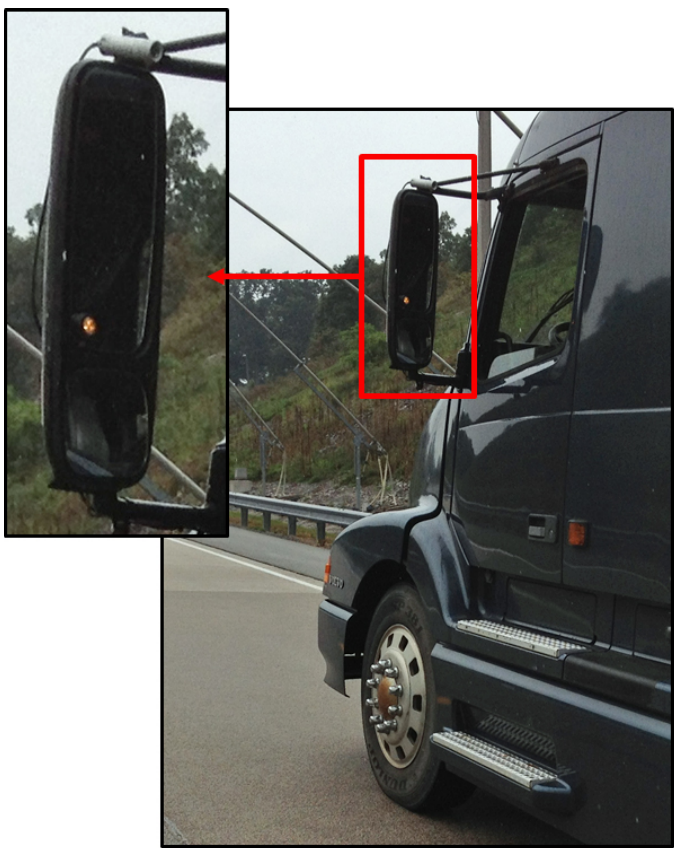

Figure 9. Image. BSW system's visual alert mounted on flat mirror.

Figure 10. Photo. Two light vehicles and a motorcycle (confederate vehicles) used as primary objects for detection.

Table 4. Quasi-static testing experimental vehicle dimensions.

Experimental Vehicle	Length	Width	Height
Motorcycle	83 in. (210.82 cm)	25 in. (63.5 cm)	55 in. (139.7 cm); 70 in. (177.8 cm) with rider
Compact Light Vehicle	156 in. (396.24 cm)	71 in. (180.34 cm)	46 in. (116.84 cm)
Mid-sized Sedan	197 in. (500.38 cm)	82 in. (208.28 cm)	58 in. (147.32 cm)

Procedure

The first effort involved calculating the FOVs afforded by the experimental CUT mirrors for drivers of different statures (5th percentile female and 95th percentile male). This was performed for the experimental CUT flat and convex mirrors. Drivers used both eyes during mirror FOV measurements. Drivers adjusted the left and right flat mirrors so that the edge of the trailer was slightly in view, and the left and right convex mirrors to include the rear of the tractor and the edge of the trailer. The drivers were instructed to maintain a normal driving posture, viewing their mirrors during testing using only a minimal head turn or upper body shift. Testing was done statically. An experimenter walked out from the back edge of the trailer holding a stick with a section identified as the target at 48 inches (122 cm) above the ground. Through radio communication with the driver, the experimenter stopped when the limits of coverage by the mirrors were reached. Appropriate measurements were then collected. In addition, measurements were taken on mirror size, curvature (for convex mirrors only), and distance from the driver head position. All measurements were used to calculate the mirror FOVs for each driver type (see Figure 11, Figure 12, and Figure 13).

The second effort consisted of determining the driver's visual detection zones afforded by the experimental CUT mirrors for the three experimental vehicles. The tester slowly drove the experimental vehicle alongside the CUT (right and left adjacent lanes) with the vehicle centered at 3 ft (0.91 m) increments from the side of the experimental CUT. Through communication with the driver, the experimenter collected approximate measurements when the vehicle was outside the driver's indirect vision. This procedure was repeated for all three types of experimental vehicles (motorcycle, compact light vehicle, and mid-sized sedan).

The research team then used the identical procedure from the second effort to determine the BSW system's detection zones for each of the three experimental vehicles.

2.1.1.2 Results

Figure 11, Figure 12, and Figure 13 depict the overlaying areas of the drivers' direct FOV from a normal driving posture, the drivers' indirect FOV through the experimental CUT's mirrors, drivers' visual detection zones afforded by the experimental CUT mirrors for the three experimental vehicle types, and the BSW system's detection zones. Each figure provides a key to describing the various regions. It is important to note that the red, cross-hatched, no-bordered boxes represent the positions and portions of the experimental vehicle when it was completely obscured from the drivers' direct and/or indirect view. In addition, a representation of one of the experimental vehicles was inserted in the mappings only when that vehicle could be completely lost from the drivers' direct or indirect vision.

2.1.1.3 Discussion

The results indicate that the BSW system provided important coverage on the extended passenger-side blindspot area directly adjacent to the tractor and the front third of the trailer. The BSW system also supplemented the passenger-side with coverage forward of the tractor where there was a large blindspot created by the tractor's hood and cab structure. As Figure 11, Figure 12, and Figure 13 depict, these passenger-side blindspots are important because they have the propensity to conceal an entire light vehicle (i.e., sedan, sports car, and motorcycle) from the driver's vision. This result is consistent with previously cited research findings that estimate that blindspot detection technology, such as the subject BSW system, could potentially address 39,000 (about 10 percent) of the estimated 384,000 annual crashes involving large trucks.(16)

However, controlled testing showed two additional regions where blindspot coverage was not fully addressed by the tested BSW system. First, the driver-side BSW system's sensor unit leaves a narrow area directly adjacent to the tractor uncovered, which could result in a false negative detection error especially with small vehicles such as motorcycles operating in that region. On both the driver- and passenger-sides, the BSW system does not provide coverage for the rear two-thirds of the trailer for about half of the adjacent lanes (an area where the FOV of the flat mirrors is limited). CMV drivers tend to rely on flat mirrors to spot adjacent vehicles and to perceive their associated speeds. Because the convex mirror provides a minified view around the vehicle, drivers may prefer the use of planar mirrors for quickly spotting adjacent traffic. This is consistent with the findings of Mortimer and Jorgeson (17) who found that drivers used a planar mirror more frequently (in terms of number and duration of eye glances) as compared to a convex mirror, and Mourant and DeNald (18) who found that drivers made quicker detections when viewing stimuli through planar mirrors as compared to mirrors with varying convexity.

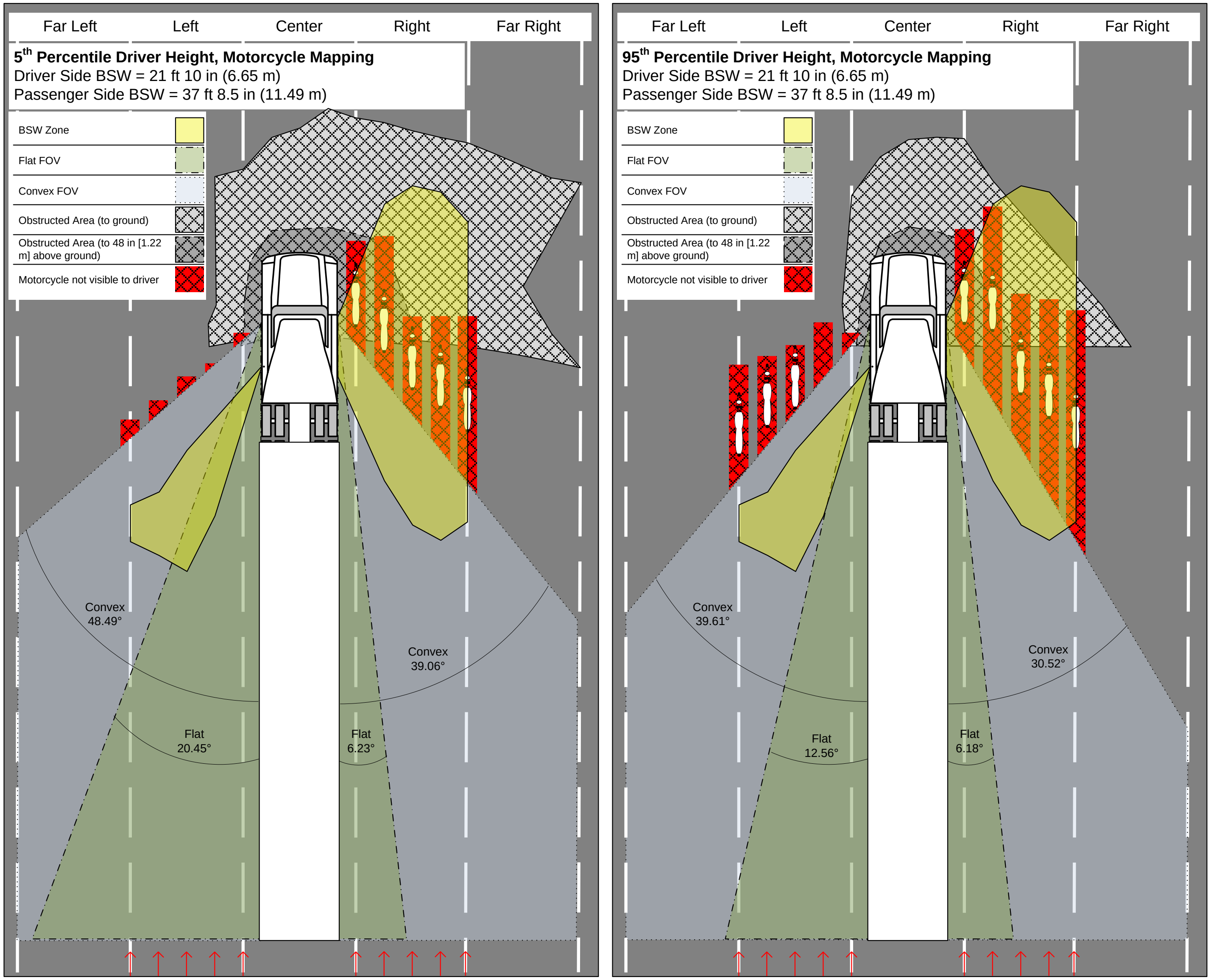

Figure 11. Diagram. Motorcycle detection zone mapping for drivers and the BSW system.

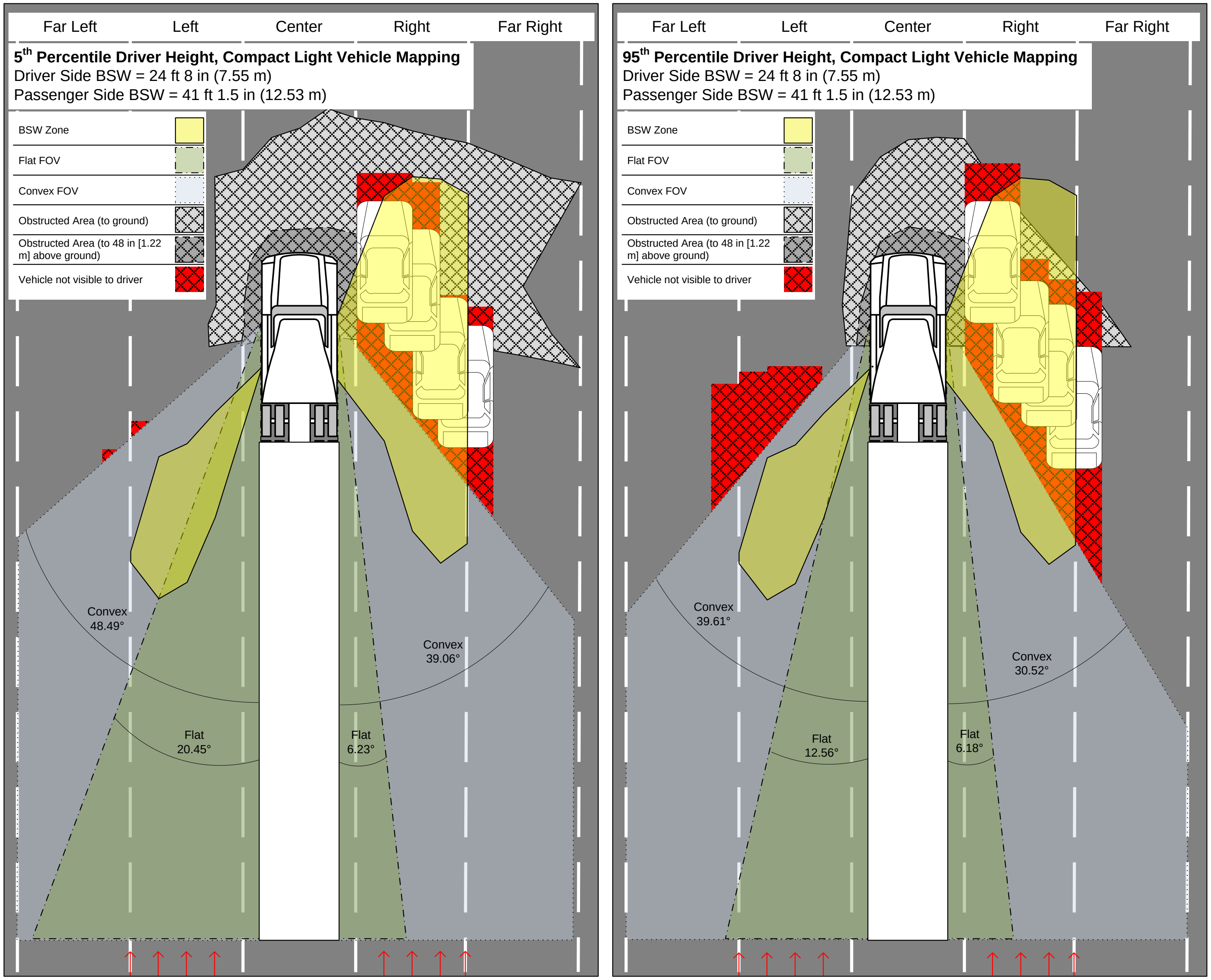

Figure 12. Diagram. Compact light-vehicle detection zone mapping for drivers and the BSW system.

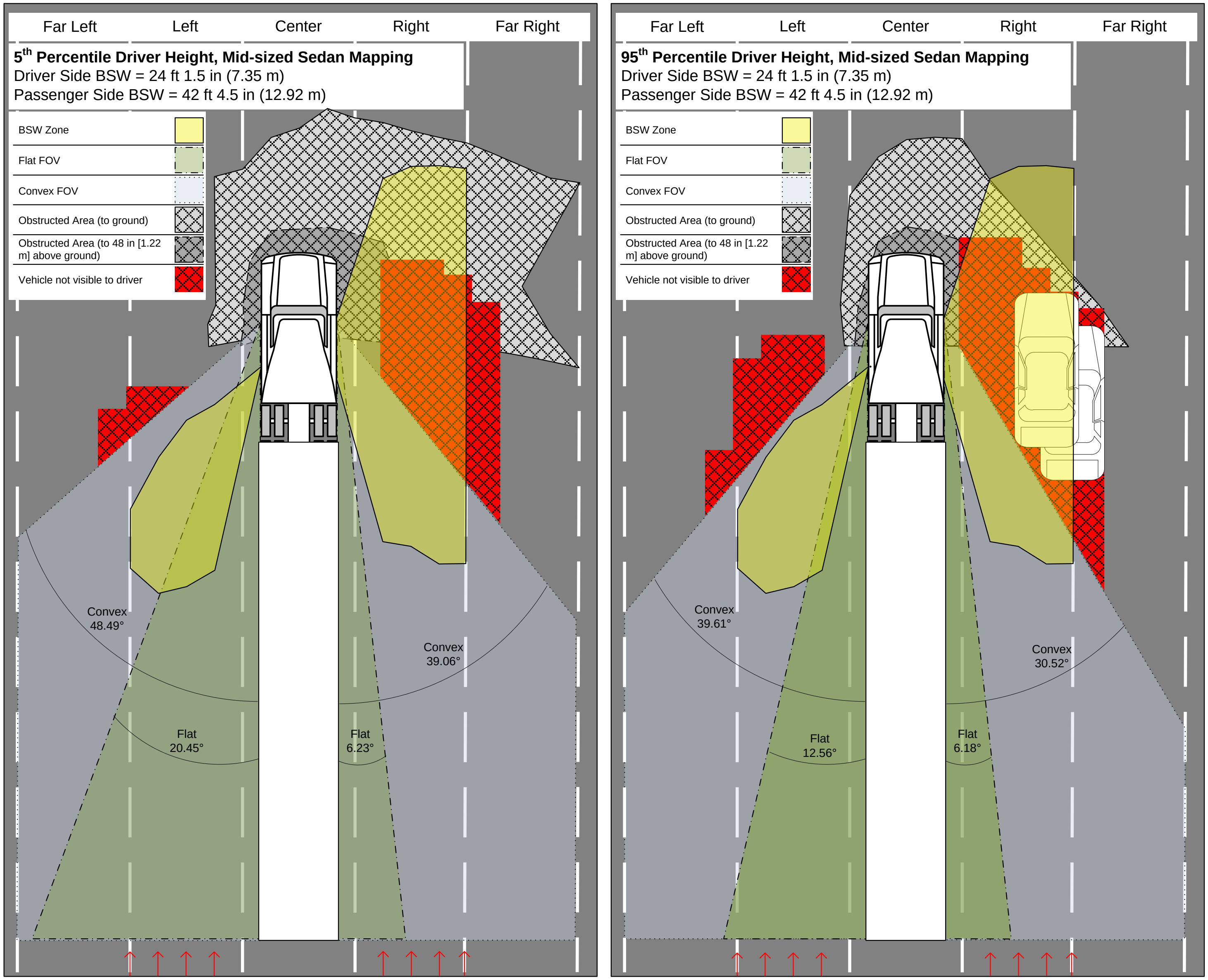

Figure 13. Diagram. Mid-sized sedan detection zone mapping for drivers and the BSW system.

2.1.2 Object Detection Performance

The research team designed an effort to test the detection performance of the BSW system around the experimental CUT. The experimental CUT remained stationary on an asphalt test pad while experimental vehicles performed approaching and passing maneuvers. The purpose of the testing was to evaluate the correct detection and rejection performance of the BSW system.

2.1.2.1 Method

Study Design

All testing was performed with trained researchers and engineers. A signal detection theory experimental design was used.(19,20) Four occurrences of detection were categorized:

- Correct detections.
- Missed detections.
- False alarms.
- Correct non-detections.

The main dependent variable (DV) was light activation (*Yes* or *No*). The main independent variables (IVs) were experimental vehicle type, closing speed, and experimental vehicle approach. All IVs were counterbalanced equally. Each scenario was performed four times. This method has been shown to be successful for evaluating system performance in a previous FMCSA-funded study that evaluated a rear-end collision warning system for heavy trucks.(21) The different levels of each IV are shown below:

- Experimental Vehicle Type.
  - Motorcycle.
  - Compact Light Vehicle.
  - Mid-sized Sedan.
- Closing Speed.
  - 5 mi/h (8.05 km/h).
  - 10 mi/h (16.09 km/h).
  - 15 mi/h (24.14 km/h).
- Experimental Vehicle Approach.
  - Rear.
    - Left Lane.
    - Far Left Lane.
    - Far Left Lane Merge.
    - Right Lane.

  - Far Right Lane.
  - Far Right Lane Merge.
  - Same Lane Rear.
- Front.
  - Left Lane.
  - Far Left Lane.
  - Far Left Lane Merge.
  - Right Lane.
  - Far Right Lane.
  - Far Right Lane Merge.
  - Same Lane Front.

Table 5 shows the parameters of the signal detection paradigm used for testing.

Table 5. Detection paradigm parameters for blindspot detection system static testing.

Light Activation	Activation Approach	Non-activation Approach
Yes	Hit (Correct Detection)	False Alarm
No	Miss (Missed Detection)	Correct Rejection (Correct Non-detection)

<u>Apparatus</u>

The same vehicles that were used during the object detection zone mapping effort were also used in the BSW system detection performance testing (experimental CUT, Figure 6; three experimental vehicles, Figure 10).

<u>Procedure</u>

The experimental CUT was positioned in the center of a six-lane asphalt pad located at the research team's facility. Figure 14 shows an overhead diagram of the multiple scenarios performed. Scenarios are described below the figure corresponding to each labeled vehicle in the diagram. During experimental vehicle approaches from the front, light vehicles approached backwards and the motorcycle approached forwards (the motorcycle used did not have reverse capabilities).

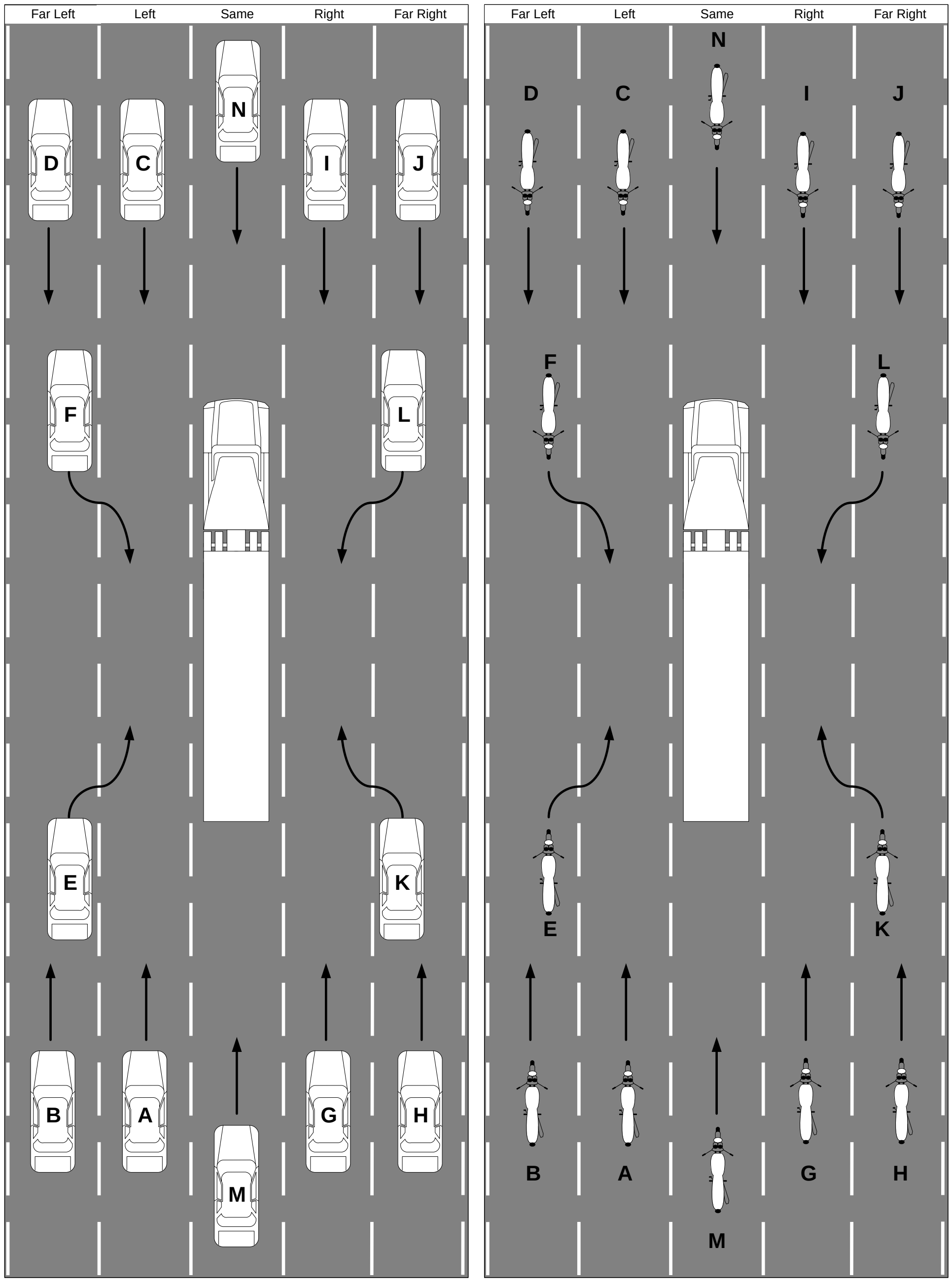

Figure 14. Diagram. Experimental vehicle approach scenarios for quasi-static testing.

- **Scenario A (Activation Approach)**: Experimental vehicle approaches from the rear in the *Left Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario B (Non-activation Approach)**: Experimental vehicle approaches from the rear in the *Far Left Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.

- **Scenario C (Activation Approach)**: Experimental vehicle approaches from the front in the *Left Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario D (Non-activation Approach)**: Experimental vehicle approaches from the front in the *Far Left Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario E (Activation Approach)**: Experimental vehicle approaches from the rear in the *Far Left Lane* and merges into the *Left Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario F (Activation Approach)**: Experimental vehicle approaches from the front in the *Far Left Lane* and merges into the *Left Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario G (Activation Approach)**: Experimental vehicle approaches from the rear in the *Right Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario H (Non-activation Approach)**: Experimental vehicle approaches from the rear in the *Far Right Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario I (Activation Approach)**: Experimental vehicle approaches from the front in the *Right Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario J (Non-activation Approach)**: Experimental vehicle approaches from the front in the *Far Right Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario K (Activation Approach)**: Experimental vehicle approaches from the rear in the *Far Right Lane* and merges into the *Right Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario L (Activation Approach)**: Experimental vehicle approaches from the front in the *Far Right Lane* and merges into the *Right Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario M (Non-activation Approach)**: Experimental vehicle approaches from the rear in the *Same Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.
- **Scenario N (Non-activation Approach)**: Experimental vehicle approaches from the front in the *Same Lane* 4 times at each closing speed (*5 mi/h*, *10 mi/h*, and *15 mi/h*), resulting in 12 approaches in total.

2.1.2.2 Results

There were 168 approach scenarios for each experimental vehicle type (504 total approach scenarios). Results indicated that all activation approaches were correctly detected and all non-activation approaches were correctly rejected (Table 6). Therefore, the estimated probability of the system correctly detecting a light vehicle located in the BSW system's detection zone was 100 percent, P(hit) = 288/288 = 1.0. The estimated probability of the system correctly rejecting a light vehicle located outside the BSW system's detection zone was 100 percent, P(cr) = 216/216 = 1.0.

Table 6. Detection paradigm results for BSW system quasi-static testing.

Light Activation	Activation Approach	Non-activation Approach
Yes	288	0
No	0	216

2.1.2.3 Discussion

Results from the quasi-static testing indicated that the BSW system performed well at accurately detecting light vehicles of different types and sizes when present in the detection zone. In addition, the BSW system performed well at accurately rejecting light vehicles of different types and sizes when approaches were not in the detection zone. It is important to note that although these results are extremely positive, they are only indicative of system performance when the equipped vehicle (in this case, the experimental CUT) is stationary on the roadway.

2.2 DYNAMIC TESTING (VIRGINIA SMART ROAD)

Additional preliminary performance testing was also performed in a dynamic setting on the Virginia Smart Road. All dynamic testing was performed with trained researchers and engineers. Two testing efforts were performed: tractor-trailer articulation and lane-change/merge scenarios.

2.2.1 Tractor-trailer Articulation

One unique characteristic of CUTs is their articulation capability. During turning maneuvers, a tractor-mounted BSW system may detect its trailer and alert the driver to a threat, leading to false alerts. An initial effort was conducted to evaluate the behavior of the BSW system during tractor-trailer articulation. Four turning maneuvers at very low speeds were performed on both the driver-and passenger-sides of the experimental CUT. When the system provided a visual alert, the angle of articulation was noted at the visual alert onset.

2.2.1.1 Results

As shown in Figure 15, the resulting mean value of the four driver-side articulations for visual alert onset was approximately 151 degrees. The resulting mean value of the four passenger-side articulations for visual alert onset was approximately 137 degrees.

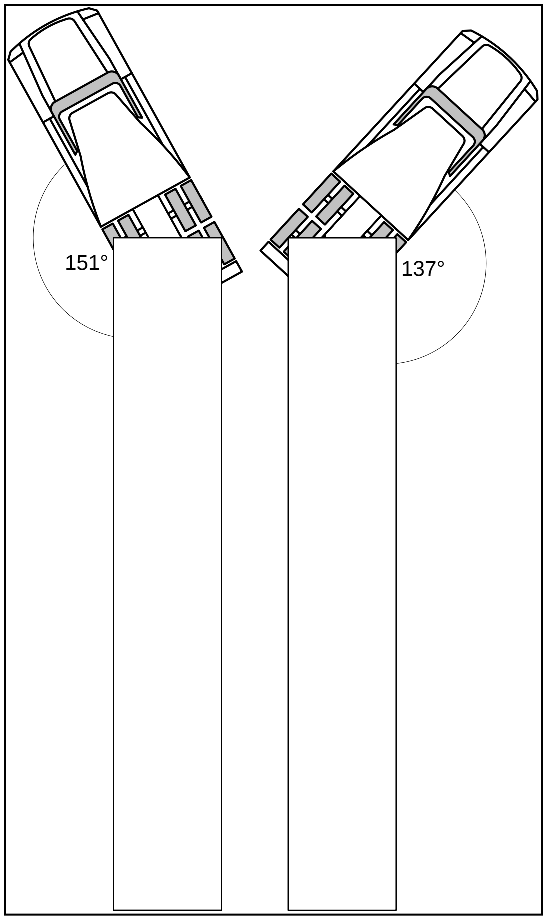

Figure 15. Diagram. Driver-side and passenger-side CUT articulation visual alert onset results.

2.2.1.2 Discussion

The purpose of this test was to determine the system's propensity for false alarms triggered by the articulation of the tractor and trailer. The results indicate that the BSW system did produce warnings during slow-speed maneuvers with shallow tractor-trailer articulation angles. However, the angles at which such warnings occurred indicate that false detections of this nature would not be expected at highway speeds and could occur only at low-speed, sharp-turn conditions. This finding appears to be an improvement to the results of the Integrated Vehicle-based Safety Systems (IVBSS) Heavy Truck Field Operation Test (FOT). The IVBSS final report stated that more than 50 percent of side-hazard alerts were issued with no targets present in adjacent lanes. According to the authors, many of these false alarms were attributed to reflections from the trailer body articulations for double-trailer configurations.[22]

2.2.2 Passing/Merge Scenarios

The BSW system detection performance was also investigated in dynamic scenarios. The experimental CUT maintained a speed of 25 mi/h (40 km/h) on the Virginia Smart Road. Two mid-sized sedans and one motorcycle were used across multiple scenarios as the primary objects for detection. Similar to quasi-static testing, a signal detection theory experimental design was used.[23, 24] Three out of four categories of occurrences of detection were used: correct detections, missed detections, and false alarms. The category of "correct non-detections" was not used, as the Virginia Smart Road contains only two lanes for testing; therefore, all light-vehicle and motorcycle passing maneuvers were in an adjacent lane and considered visual signal-activation scenarios. The missing category (correct non-detections) was previously examined during quasi-static testing.

A robust BSW system is expected to provide accurate information under a variety of weather conditions. To evaluate the performance of the BSW system under inclement weather conditions, system performance tests were also conducted in rainy conditions on the Smart Road. All scenarios previously described were repeated in the rain (with the exception of the merging and motorcycle scenarios). The removal of the excepted merging scenarios in rainy conditions was due to the lack of rain tower availability near the merging locations on the Smart Road, and the removal of motorcycle scenarios under rainy conditions was for safety reasons.

The main DV was light activation (*Yes* or *No*). The main IVs were the number of light vehicles, the motorcycle, rain, and the light-vehicle approach scenario. All light-vehicle approaches were at 35 mi/h (56 km/h) for rear approaches, and 15 mi/h (24 km/h) for front approaches. Each scenario was performed four times. The different levels of each IV are shown below:

- One Light Vehicle.
  - Rear.
    - Left Lane (Rain & Clear).
    - Left Lane Merge (Clear Only).
    - Right Lane (Rain & Clear).
    - Right Lane Merge (Clear Only).
  - Front.
    - Left Lane (Rain & Clear).
    - Right Lane (Rain & Clear).
- Two Light Vehicles.
  - Rear.
    - Left Lane (Rain & Clear).
    - Left Lane Merge (Clear Only).
    - Right Lane (Rain & Clear).
    - Right Lane Merge (Clear Only).
  - Front.
  - Left Lane (Rain & Clear).
  - Right Lane (Rain & Clear).
- Motorcycle.
  - Rear.

    - Left Lane (Clear Only).
    - Left Lane Merge (Clear Only).
    - Right Lane (Clear Only).
    - Right Lane Merge (Clear Only).
  - Front.
    - Left Lane (Clear Only).
    - Right Lane (Clear Only).

Figure 16 shows overhead diagrams of each left lane, single-vehicle scenario performed (all right lane scenarios were performed in a similar manner). Figure 17 shows overhead diagrams of each left lane, two-vehicle scenario performed (all right lane scenarios were performed in a similar manner).

2.2.2.1 Results

Of the 72 total maneuvers performed on the Smart Road, 32 were performed in rainy conditions and the remaining 40 were performed in clear conditions. Of the 32 maneuvers performed in the rain, the BSW system correctly identified all 32. Therefore, the estimated probability of the system correctly identifying a vehicle entering the target area in rainy conditions was 100 percent, P(hit) = 32/32 = 1.0. Although no missed detections occurred during maneuvers, two false alarms were observed between maneuvers (i.e., while re-positioning a test vehicle for the next maneuver) when no other objects/vehicles were present. It is hypothesized that these false alarms occurred due to the system falsely identifying rain spray from the experimental CUT as an object.

Of the 40 maneuvers performed in clear conditions, the BSW system correctly identified targets in 38 maneuvers. Therefore, the estimated probability of the system correctly identifying a vehicle entering the target area in clear conditions was 95 percent, P(hit) = 38/40 = 0.95. The two missed detections were during motorcycle left-to-right merge maneuvers which were not conducted in rainy conditions.

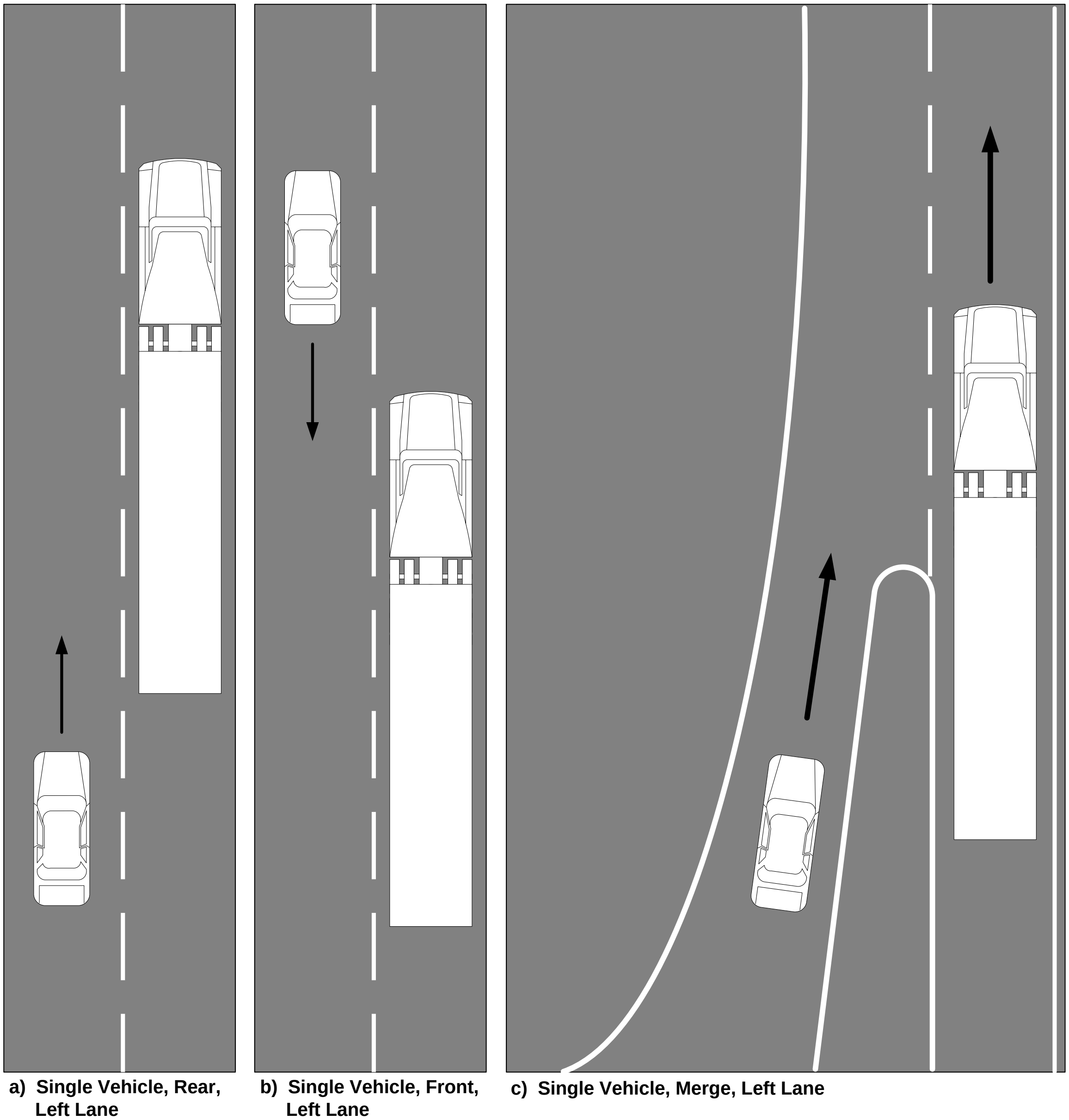

Figure 16. Diagram. Single-vehicle, left lane, light-vehicle approach scenarios for dynamic testing (not to scale).

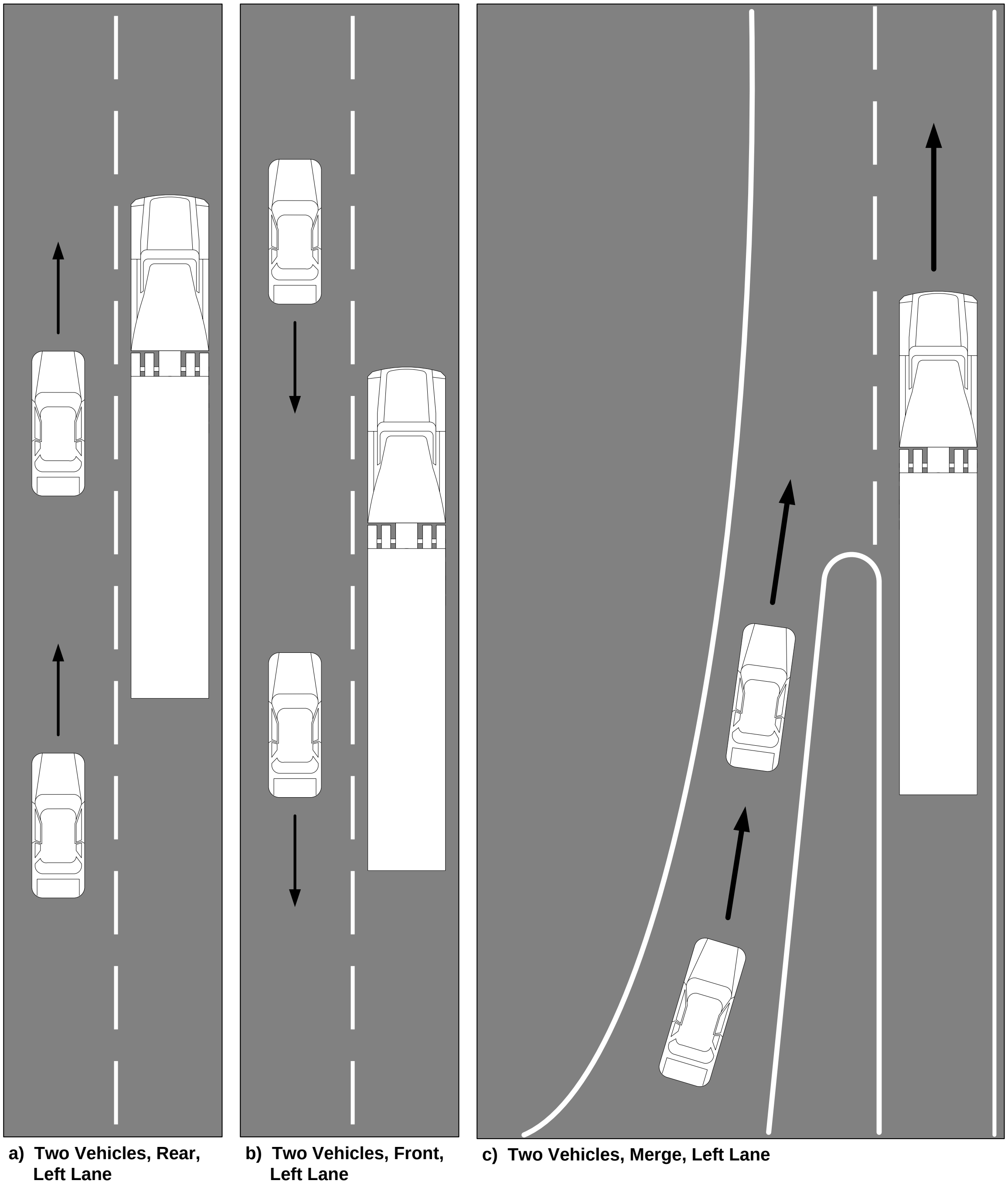

Figure 17. Diagram. Two vehicles, left lane, light-vehicle approach scenarios for dynamic testing (not to scale).

2.2.2.2 Discussion

Results of this dynamic test found that the BSW system performed suitably in detecting light vehicles of different types and sizes when present in the detection zone under varying conditions (multiple vehicles present, rain, and varying light-vehicle approach scenarios). There were two conditions that seemed to create challenges for the subject system; namely, false detections during rain and missed detections with small vehicle approach angles that most likely result from positioning the vehicle between the BSW system's laser beams. The latter missed detection is likely a phenomenon observed during controlled experiments when the experimental CUT was stationary. It is unlikely in a real-world driving scenario that a light vehicle or other object would remain within this narrow target (between the system's laser beams) in the CMV's blindspot area for an extended period of time.

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3. FIELD STUDY

The effectiveness of the BSW system was investigated using a naturalistic driving study methodology. Naturalistic, or *in situ*, data collection for the CMV industry involves truck drivers operating vehicles that have been instrumented with data collection equipment, including sensors and video cameras, to record driving performance data during normal revenue-producing routes. This approach provides the significant advantage of recording all activity prior to, during, and after a crash or near-crash. Data recorded prior to a critical incident (CI) allows analysts insight on why an incident may have occurred and potentially what could have been done to prevent it from happening. The naturalistic data collection approach was selected for this particular field study for its abilities to evaluate the safety benefits and potential unintended consequences of using the BSW system, to explore driver acceptance, and to monitor overall system performance and reliability.

Two efforts were performed in parallel to investigate the safety benefits of the BSW system (Figure 18). The first effort used a before/after study design to compare drivers' performance before the BSW system's warnings were enabled (baseline) with their performance after the system warnings were enabled (intervention). The second effort explored the feasibility of comparing fleet-owned crash data before and after the BSW system implementation.

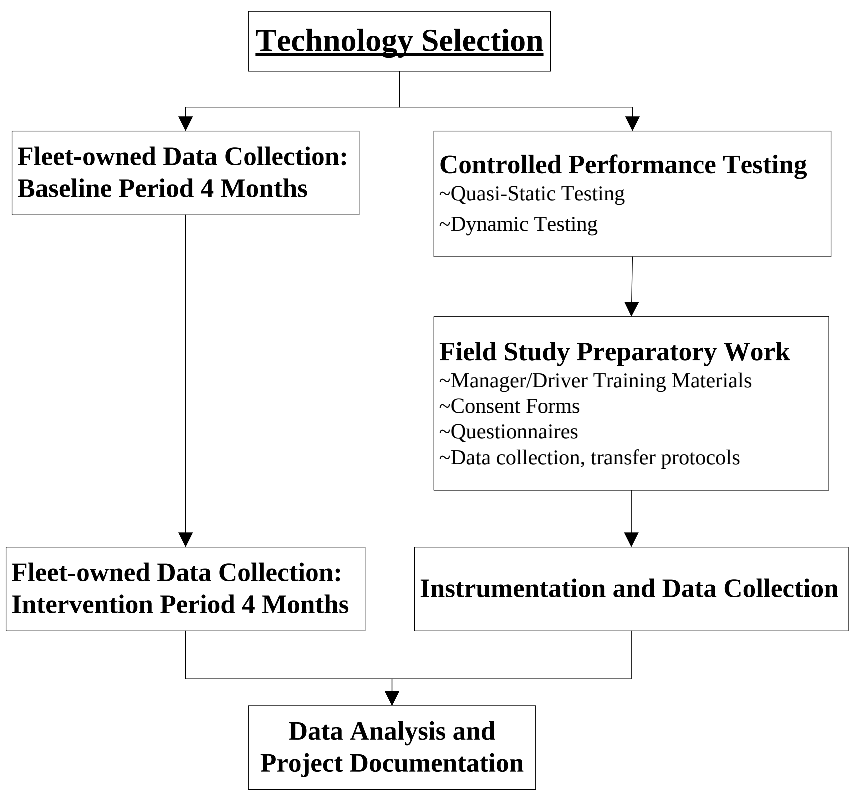

Figure 18. Flowchart. Blindspot warning safety technology evaluation project design.

The primary safety benefit measure of interest set for the first evaluation effort was the rate of safety-critical events (SCEs) per 10,000 mi (16,093 km) of driving. SCEs consisted of all valid events which can be classified into five basic event types: crashes, tire strikes, near-crashes, crash-relevant conflicts, and unintentional lane deviations (LDs) (Table 7). The BSW system's performance was also evaluated using data collected in the effort just described. A sample of drivers and safety managers was also surveyed in order to determine user opinions established on the tested BSW system over the course of the naturalistic driving and data collection period.

Table 7. Description of SCE type.

Event Type	Description
Crash	Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated.
Crash: Tire Strike	Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated where the contact occurs on the truck's tire only. No damage occurs during these events (e.g., a truck is making a right turn at an intersection and runs over the sidewalk/curb with a tire).
Near-crash	Any circumstance that requires a rapid, evasive maneuver (e.g., hard braking, steering) by the subject vehicle or any other vehicle, pedestrian, cyclist, or animal, in order to avoid a crash.
Crash-relevant Conflict	Any circumstance that requires a crash-avoidance response on the part of the subject vehicle, any other vehicle, pedestrian, cyclist, or animal that was less severe than a rapid evasive maneuver (as defined above), but greater in severity than a normal maneuver. A crash-avoidance response can include braking, steering, accelerating, or any combination of control inputs.
Unintentional LD	Any circumstance where the subject vehicle crosses over a solid lane line (e.g., onto the shoulder) where there is not a hazard (guardrail, ditch, vehicle, etc.) present.

The second evaluation effort explored the feasibility of comparing fleet-owned crash data from the participating fleet for a period before the safety system intervention phase with the fleet-owned crash data during the intervention phase. These data were used to measure and compare the mean crash rate per vehicle miles traveled (VMT) both before and after safety system implementation.

3.1 STUDY DESIGN

The potential safety benefit of the BSW system (in relation to SCEs) was evaluated using a naturalistic driving before/after study to compare driver performance before the system was enabled with driver performance after the system had been made functional. The primary crash type most applicable to the investigation of this BSW system was lane change/merge events. Therefore, lane change/merge SCEs were used as the primary safety benefit measure for the power analysis that led to the final study design.

The power analysis was conducted using two recent heavy-vehicle data sets resulting from real-world studies to estimate the potential occurrence of lane change/merge SCEs in the current study.(25,26) These databases indicated that approximately seven lane change/merge SCEs per 75,000 mi (120,700.8 km) could be expected in the current study. The current study scope was established to include 20 CMVs collecting data over a 6-month period; however, the monthly breakdown between the baseline and intervention periods was determined through a power analysis. The mean lane change/merge SCE rate and standard deviation (SD) were computed for the purpose of performing a power analysis for a 2-month baseline period and a 2-month (at least) intervention period. The mean lane change/merge SCE rate in the baseline condition was 0.086 (SD = 0.120), while the mean lane change/merge SCE rate for the intervention condition was estimated at 0.043 (SD = 0.072). Table 8 provides results for a paired-sample, one-sided t-test that compares a baseline distribution to an intervention distribution using a nominal power value of 0.8 and a significance level of 0.05. The results are presented as the number of vehicles required for a 2-month baseline data collection period with a matched 2-month (at least) treatment condition. Also presented in the table are correlation values which indicate the level of positive correlation that is assumed for drivers' SCE rates in their baseline to treatment conditions.

Table 8. Power analysis results for an A^2B^4 design using data from generated data set representative of a daytime heavy-vehicle data collection effort.

Correlation Value	Actual Power	N Pairs (# of Trucks)
0.7	0.806	27
0.8	0.804	21
0.9	0.800	15
1.0	0.831	10

The power analysis performed indicated that the number of trucks required ranged from 10 to 27 depending on the correlation value selected. Based on the power analysis performed, an A^2B^4 design was selected for the current study where "A" and "B" refer to the baseline and intervention phases, respectively. The superscript refers to the number of months in each phase (e.g., "2" refers to 2 months). It was recommended that the 20 CMVs originally scoped for the study would be satisfactory. According to the power analysis, 20 CMVs at a correlation value of just over 0.8 would provide sufficient power for statistical significance testing at the conclusion of data collection.

3.2 METHOD

3.2.1 Fleet and Drivers

The research team evaluated multiple fleets for participation in the FAST DASH program, to include fleets that have participated in previous studies with the research team, as well as new fleets. The final list of potential fleets was evaluated to select one that would meet the needs of both the research team and the BSW system technology provider. Three important factors were considered:

- The number of trucks and drivers available at the participating fleet.
- The proximity of the fleet's terminal to both teams' headquarters.

- The fleet management's ability and willingness to provide the research team fleet-owned data for exploratory analysis.

With these criteria in mind, a mid-sized fleet operating out of a terminal located in Kernersville, NC managing 98 power units (tractors) and approximately 100 drivers was selected. Of these 98 power units, 45 were assigned to a dedicated contract with the fleet's client. A broad assortment of routes was assigned to these 45 power units which consisted mostly of long-haul deliveries in North America. The group of these dedicated trucks and associated drivers was considered an excellent pool for potential recruitment of approximately 20 drivers. The participating fleet actively pursues aftermarket safety technologies for implementation in their trucks. However, prior to the current study the fleet has not had a BSW system installed on their trucks.

3.2.2 Apparatus

3.2.2.1 Trucks

A total of 20 sleeper-berth Class 8 tractors were instrumented in this study. Four were manufactured in 2009, five in 2010, and eleven in 2012. Each tractor exclusively hauled 53 ft (16m) box-van trailers during this study.

3.2.2.2 Data Acquisition System (DAS)

The research team equipped all 20 CMVs with NextGen DASs (Figure 19). The DAS captures three general groups of measures: DAS measures, vehicle network measures, and add-on measures. The add-on measures included in this first FAST DASH technology evaluation study involved the BSW system's visual alert data. During the evaluation period, the NextGen DAS collected all three groups of data to assist in determining the operational performance of the BSW system as measured by metrics such as the frequency and severity of SCEs. Data collected by the NextGen DAS initiated from vehicle "ignition on" to 5 seconds after "ignition off" and were saved continuously throughout the data collection period. The DAS data were periodically retrieved from vehicles by research team personnel only. The general design characteristics for the NextGen DAS include the following:

- Compatible with the vehicle (e.g., power obtained from vehicle battery, data from in-vehicle network).
- Unobtrusive and non-invasive.
- Not distracting.
- Does not limit driver visibility.
- No permanent modifications to the vehicle.
- Minimal space requirement (e.g., for data storage unit).
- Automatic startup, shutdown, and continuous operation.
- No subject tasks required for operation or data downloading.

- Reliable performance in the often-harsh operational environment of driving; minimal data loss and automatic detection of failures.
- Continuous multi-camera video recording system (30 Hz) to capture driver's face and rearward and forward scenes.
- Ruggedness and crash survivability.

Figure 19. Photo. The NextGen DAS.

The NextGen DAS was unobtrusively installed in vehicles to facilitate naturalistic driving behavior monitoring with the BSW system during on-road settings. The NextGen DAS equipment was instrumented behind the driver seat, concealed from the driver. Cameras mounted inside the cab were in a small protected housing located on the center of the windshield. All wires and other data recording equipment were professionally routed under interior panels.

The NextGen DAS uses a 24 GHz Universal Medium Range Radar installed on the front bumper, center position, for object tracking and ranging measurement. In addition, the DAS recorded multi-channel H.264 compressed video/audio on a custom electronics package designed specifically for automotive use. Color and black-and-white video cameras recorded three external views and one internal view. The three external views included one of the forward roadway (camera positioned on the windshield just left of center), one down the driver-side adjacent lane (camera positioned on the driver-side front fender facing rearward), and one down the passenger-side adjacent lane (camera positioned on the passenger-side front fender facing rearward) (see Figure 20). The internal view included a front view of the driver's head and shoulders (camera positioned on the windshield just left of center). Other non-video data collected included: turn signal use, other vehicle position/distance, speed, lateral and longitudinal *g*-forces, yaw rate, and 30-second audio clips resulting from drivers manually pushing a button on the instrument panel (incident button). The incident button was provided so that drivers could provide verbal comments and/or descriptions that they perceived to be relevant to the evaluation of the BSW system. The NextGen DAS interfaced with the vehicle's J1939 controller area network (CAN) Bus via the original equipment manufacturer (OEM) onboard diagnostic port to collect data such as speed, mileage, etc. The J1939 CAN Bus was directly tapped behind the dash.

Figure 20. Photo. Four camera images multiplexed into a single image.

The NextGen DAS sensors included:

- *Global Positioning System (GPS)*: A GPS device used primarily for tracking the instrumented vehicles and placing them in time and space. Data output included measures of latitude, longitude, altitude, horizontal and vertical velocity, heading, and status/strength of satellite acquisition.
- *Lane Tracker*: An in-house-developed lane tracker called the "Road Scout" was included in the NextGen DAS. The Road Scout is a custom machine vision process running concurrently on the DAS that grabs video frames from the forward camera feed. Note that the "grabbed" video frames are not stored but are instead processed algorithmically in real time to calculate the vehicle position relative to road lane markings.
- *Yaw Rate*: Three yaw rate (gyro) sensors are included in the NextGen DAS and provide a measure of steering instability (i.e., jerky steering movements).
- *X/Y/Z Accelerometer*: Accelerometers installed in the vehicle are used to measure longitudinal (x), lateral (y), and vertical (z) accelerations.
- *Vehicle Network*: The measures that can be accessed from a particular vehicle depend on the make, model, and year of the vehicle. As such, it is possible that certain measures are only available for certain instrumented vehicles. The available measures are defined in a header file in each data set. The portion of the data set that includes the vehicle network data typically contains measures of the following:

- Vehicle speed.
- Odometer.
- Ignition signal.
- Throttle position.
- Brake activation.

3.2.2.3 Blindspot Warning System Description

The technology vendor was responsible for installation of the BSW systems. The three BSW system sensor units and two BSW system visual alerts were positioned in very similar locations as they were when placed on the experimental CUT during preliminary performance testing (two sensors mounted on the passenger-side, one sensor mounted on the driver-side, visual alerts mounted on flat mirrors [Figure 7, Figure 8, Figure 9]). The exact positions of the visual alerts on the flat mirrors varied by driver due to personal preferences communicated to the BSW system installation team. Inside each cab, a single pushbutton was installed on the instrument panel for drivers (Figure 21). The purpose of the pushbutton was to provide drivers with the ability to temporarily disengage the BSW system for a period of 15 minutes. The technology vendor implemented the push-button option after feedback from their own driver testing which indicated the nuisance of the visual alerts when involved in low-speed backing maneuvers, especially at night.

Figure 21. Image. Temporary disengage pushbutton for the BSW system.

3.2.3 Driver Recruitment Process

The research team worked with the fleet safety managers to recruit drivers for participation. Safety manager assistance came in the form of delivering recruitment flyers/information via physical postings in common areas, electronic mail (email), in-person communication using an announcement script prepared by the research team, and/or through dispatch device delivery. The research team also made frequent visits to the terminal location and set up a recruitment booth. Participants were eligible for inclusion in the study if they met all of the following criteria:

- Drivers at least 21 years old (drivers must be 21 years old to obtain a commercial driver's license [CDL]).

- Able to operate a tractor-trailer.
- Willing to have video recorded of them while driving.
- Have normal or corrected-to-normal visual acuity of 20/40 or better.
- Willing to fill out tax forms and provide a Social Security number for compensation purposes.
- Willing to complete a brief demographic questionnaire, a pre-study questionnaire, and a post-study driving questionnaire to the best of their ability.
- Willing to have a training session with a fleet manager regarding the BSW system.
- Use an incident button to report any issues that arise.
- Willing to allow experimenters to check operation of the data collection equipment in the truck once a week in the first month, and once a month for the remainder of the study.
- Willing to notify researchers if they experience problems associated with the BSW system.

All study protocols were approved by the Virginia Tech Human Assurances Committee Institutional Review Board (IRB). Participating drivers read and signed an informed consent form and received $50 each week for their participation (with an additional $100 bonus for fully completing all 6 months of participation).

When drivers indicated interest in study participation, they were escorted to a private area at the terminal by a member of the research team and provided an informed consent form to review. The researcher answered any questions that each driver had prior to each party providing his/her signature on the form. The researcher explained that the BSW system would be deactivated for at least the first 2 months of participation; however, the research team's DAS would be recording video and kinematic data and the participant should drive as he or she normally would. Participants were also instructed that after the BSW system was activated, a fleet safety manager would provide a review of the system functionality and any training necessary to operate the system. Drivers were also instructed that audio would be recorded only when an incident button located on the instrument panel was pushed by the participant. The activation of the incident button would start a 30-second audio recording.

After the informed consent form was signed by both parties, each driver was required to show a valid Class-A CDL, and then a brief screening interview was completed. A test for visual acuity (Snellen test) was completed to ensure that visual acuity was within the legal driving limit (corrected to 20/40). A tax form was also signed for compensation purposes. Upon completion of all screening activities, a sample of seven drivers filled out a pre-study questionnaire (see Appendix C).

After a participant completed all pre-study forms and/or questionnaires, the corresponding tractor operated by the participant was installed with the research team's DAS and the BSW system. When both the DAS and the BSW system had been installed, the participant's data collection period began. The research team met with participants, usually at the participating fleet's maintenance terminal, to retrieve data collected from the instrumented vehicles. Data were retrieved through the use of removable hard drives used to store video, audio, and dynamic sensor data from the DAS. These hard drives were installed in a lockable bay interface on the DAS. Each drive was secured in the DAS with a key (keys were only accessible to research team personnel). All participants had their hard drives removed and replaced with new ones approximately every 1–3 weeks. Although the BSW system was installed and operational, the visual alerts were not installed on the mirrors until the research team could ensure that 2 calendar months of valid data had been collected by the DAS, which serves as the baseline period for that driver. At this time, the visual alerts were positioned on the flat mirrors (on a participant-by-participant basis). This constituted the end of the baseline period and the beginning of the intervention period for that driver. Data collection ended when the research team ensured that at least 4 calendar months of valid data had been collected by the DAS.

Upon completion of the intervention stage, the same seven participants that completed a pre-study questionnaire also completed a post-study questionnaire (see Appendix D). Participants were then provided with their final compensation and their tractor's DAS was shut off. The technology vendor was then notified of the participant's completion so that the BSW system could be removed (if approved by management).

One fleet manager was also recruited to participate in a post-study interview. The manager was provided an informed consent form which was signed by both parties. Questions asked by the research team during this interview can be found in Appendix E. No compensation was provided to the fleet manager for his participation.

3.2.4 Data Reduction

3.2.4.1 Participant Verification

Each file recorded by the DAS was reviewed to verify that the participant was indeed operating the vehicle. Any drivers recorded that were not official participants in the study were excluded from further reduction.

3.2.4.2 Data Quality Control and Safety-critical Event Reduction

A data quality control process was performed once data files were successfully transferred to the database. The data were reviewed to verify correct synchronization of video to sensor data. Then, several files from each hard drive were selected for a more detailed review to assess the quality and integrity of all inputs considered necessary for proper event identification (i.e., sensor data necessary for data set scanning using the triggers described below).

Data reduction was performed in order to identify valid SCEs within the established calendar dates for the baseline and intervention conditions on a per-driver basis in an effort to meet the A^2B^4 study design. SCEs of interest included crashes, near-crashes, crash-relevant conflicts, and unintentional LDs. Events of interest were identified by scanning the data set for notable actions, such as hard braking and LDs. To identify these actions, threshold values in matrix laboratory (MATLAB) code ("triggers") were set based on previous heavy-truck naturalistic studies. The FAST DASH research team implemented six SCE triggers in the data reduction effort. Trigger values and thresholds reported below were set low so that fewer valid events would be missed by the scan. These six SCE triggers are further described below:

- **Longitudinal Acceleration (LA)—**Hard braking or sudden acceleration $\leq$ -0.2 g, and speed $\geq$ to 3.5 mi/h (5.63 km/h) (all for at least 0.1 s within a time interval of 0.1 s).
- **Lane Deviation (LD)—**Any time the truck aborts the lane line and returns to the same lane without making a lane change (distance from center of lane to outside of lane line < 55.12 inches [140 cm]) at a speed > 24.61 mi/h (39.6 km/h).
- **Time-to-collision (TTC)—**The amount of time (in seconds) that it would take for two vehicles to collide if one vehicle did not perform an evasive maneuver in $\leq$ 2 s, coupled with a range of less than or equal to 250 ft (76.2 m), a target speed of $\geq$ 5 mi/h (8.05 km/h), a yaw rate of less than or equal to $|6°/s|$, and an azimuth of less than or equal to $|0.12°|$ (all for at least 0.1 s within a time interval of 0.1 s).
- **Swerve (S)—**A sudden "jerk" of the steering wheel to return the truck to its original position in the lane (S value of $\geq$ 2 rad/s^2, and a speed $\geq$ to 5 mi/h [8.05 km/h]) (all for at least 0.1 s within a time interval of 0.1 s).
- **Critical Incident (CI) Button—**A self-report by the driver of an incident activated by pressing a button located on the instrument panel.
- **Analyst-identified (AI)—**An event that is identified by the analyst but has not been identified by an SCE query.

Once the above triggers were run across the data, each generated trigger was reviewed to determine if it was an event of interest (i.e., a valid event). Valid triggers were defined as those where recorded dynamic-motion values actually occurred, were verifiable in the video and other sensor data, and where the trigger could be grouped into one of the previously noted event classifications (one or more valid triggers may have been included in an SCE). Invalid triggers were those triggers where sensor readings were spurious due to a transient spike or some other anomaly (false positive), or where there was no conflict (e.g., the driver braking hard for a stop sign, with no surrounding traffic). Invalid triggers were not analyzed any further. Valid triggers were confirmed to be valid by experienced reductionists who then answered questions specific to each event including conflict- and environment-related questions. A second round of validation occurred by an experienced reductionist. The experienced reductionist used in the current study has extensive experience in naturalistic driving data reduction, specifically SCE validation and conflict scenario reduction. After a final set of validated SCEs was compiled, the research team's Principal Investigator (PI) and Project Manager (PM) reviewed each one and pulled those that were deemed lane change/merge-related for a follow-on analysis specifically related to the BSW system.

3.2.4.3 Random Data Sampling to Assess Blindspot Warning System Performance

An evaluation of the BSW system performance was conducted by sampling a portion of data from each driver during each week of participation in the intervention stage. This effort was conducted to assist in validating the accuracy of the BSW system and required the use of video and kinematic data. Although system performance had been evaluated in quasi-static and dynamic closed-test-track research prior to the field study, an evaluation of sampled data from the real-world data collection effort was also necessary to verify in-service performance. For this purpose, system performance was examined by sampling data from all drivers during the intervention periods.

A meaningful data sampling approach was necessary given that the field study generated approximately 439,404 mi (707,152 km) of valid intervention data. Trained reductionists identified 5 mi (8km) of daytime and 5 mi (8 km) of nighttime driving periods per week for each driver (if available). The resolution of the data for reduction was equal to 1 ms and will be referred to as "time syncs" for the remainder of this report. During each 5-mile section, 10 random time syncs were selected for reduction using a random number generator (no time syncs were repeated). At each identified time sync, a snapshot of the video and the BSW system's visual alert data were evaluated. Reductionists answered the following questions at each identified time sync for both the driver- and passenger-sides:

- Has the BSW system visual alert been activated?
- Is there a vehicle present inside the BSW system detection zone?
- Is there a vehicle present outside the BSW system detection zone?
- Is there an object present inside the BSW system detection zone?
- Is there an object present outside the BSW system detection zone?
- Please describe the vehicle/object identified (if any).
- Please provide any notes you feel are necessary to justify your answers to the above questions.

After reductionists completed their evaluation of all events, a second round of the assessment validation process was conducted by the research team's PM. The PM evaluated a sample of the reductionists' results by randomly selecting an event during each week for each driver. In addition, all false alarms and all missed detections found by reductionists were evaluated by the research team for accuracy.

3.3 RESULTS

3.3.1 Participant Demographics

A total of 21 drivers were recruited over the 11-month data collection period (1 female, 20 males). The research team collected baseline data from all 21 drivers. Of these 21 drivers, 19 successfully completed their 2-month baseline condition participation. Of these 19 drivers, 18 collected data in the intervention condition. Of these 18, 16 successfully completed the full 4-month intervention condition. The mean age of all drivers at the beginning of participation was 50.71 years (SD = 7.95). Their mean years of driving experience was 17 (SD = 12.34), resulting in a total of 357 years of driving experience for the study population.

Due to the Paperwork Reduction Act (PRA), there are limitations on the number of study participants that can fill out surveys and/or questionnaires (no more than nine participants are allowed to fill out questionnaires/surveys without a special waiver from Office of Management and Budget [OMB]). Therefore, only seven drivers and two safety managers were selected to fill out questionnaires in the FAST DASH study. The seven randomly selected drivers filled out pre-study and post-study questionnaires containing rating scales and open-ended questions. Of the two safety managers that were recruited, only one successfully completed the post-study questionnaire. All of these questionnaires can be found in Appendices B and C.

3.3.2 Naturalistic Data Statistics

The research team collected approximately 722,639 mi (1,162,975 km) of on-road data over a calendar period of approximately 11 months. (A data collection period of 11 months was necessary for a substantial number of drivers to complete the 2-month baseline and 4-month intervention conditions.) The 722,639 mi (1,162,975 km) of on-road data collected is equivalent to 260 transcontinental trips between Los Angeles, CA and New York, NY (283,235 mi [455,823 km] of baseline and 439,404 mi [707,152 km] of intervention).

3.3.3 Safety Evaluation (Safety-critical Event Analysis)

During data reduction, a total of 220 SCEs were identified by analysts across all participating drivers with valid data (108 in baseline, 112 in intervention). However, three participants who collected valid data in the baseline condition did not go on to collect valid data in the intervention condition. Because these drivers did not have both baseline and intervention data, their baseline SCEs and mileage were removed from the data set before analysis. After removing these drivers' SCEs and mileage, a total of 211 SCEs (99 in baseline, 112 in intervention) were available for analysis across 722,639 mi (1,162,975 km); 283,235 mi (455,825 km) in baseline, and 439,404 mi (707,152km) in intervention. These events were classified by event type:

- 1 Crash.
  - Baseline = 0.
  - Intervention = 1.
- 47 Tire Strikes.
  - Baseline = 23.
  - Intervention = 24.
- 34 Near-crashes.
  - Baseline = 10.
  - Intervention = 24.
- 119 Crash-relevant Conflicts.
  - Baseline = 60.
  - Intervention = 59.
- 10 Unintentional LDs.

- Baseline = 6.
- Intervention = 4.

Two analyses were performed using the SCEs above to evaluate the safety benefit of the BSW system. First, an analysis was performed comparing all baseline SCEs to all intervention SCEs. Next, SCEs were filtered for inclusion of only lane change/merge conflicts, again comparing baseline to intervention conditions. Each analysis is described below in its respective section.

3.3.3.1 Analysis of All SCEs: Baseline Versus Intervention

As previously mentioned, there were 99 SCEs identified over 283,235 mi (455,823km) in the baseline condition, and 112 SCEs identified over 439,404 mi (707,152km) in the intervention condition. SCE rates per 10,000 mi (16,093km) were then calculated for each condition resulting in the following (see Figure 22):

- Baseline = 3.50 SCEs per 10,000 mi.
- Intervention = 2.55 SCEs per 10,000 mi.

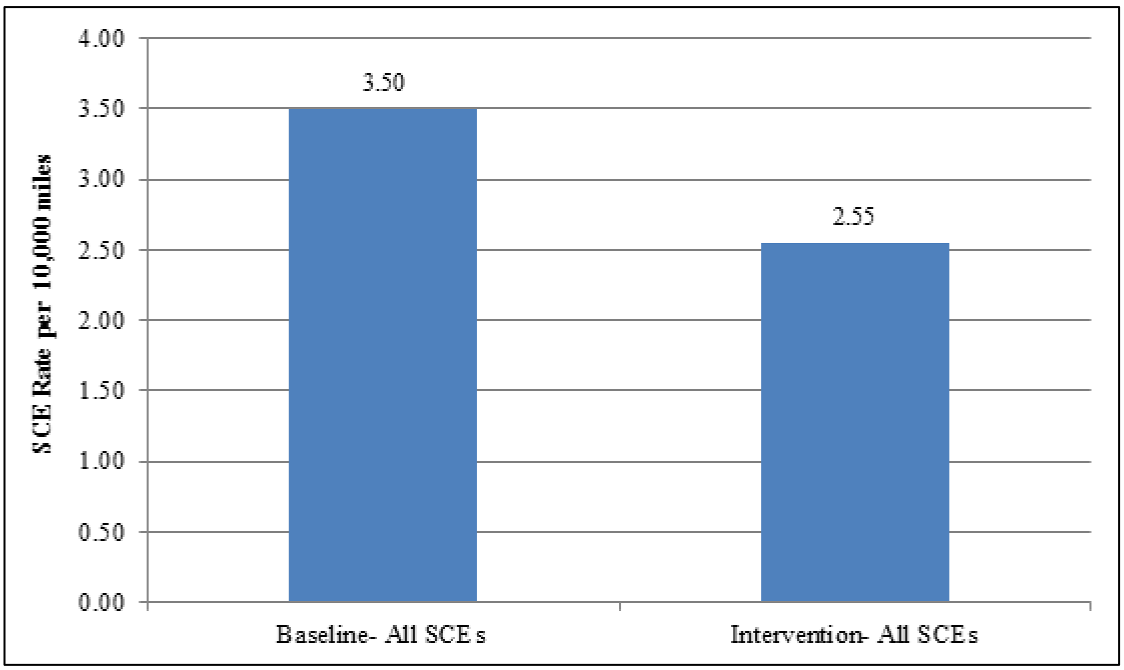

Figure 22. Bar chart. SCE rates for all SCEs across baseline and intervention.

The research team calculated the difference in SCE rates between the baseline and intervention conditions for each driver. The average reduction in SCE rate was 0.66 SCEs per 10,000 mi (16,093km) (Standard Error [SE] = 0.58). Testing the results for normality indicated that the distribution was not normal (Shapiro-Wilk statistic $W = 0.83$, $p = 0.0036$). Therefore, a non-parametric statistical test was selected to analyze the data. The nonparametric test chosen was a Wilcoxon Signed Rank test. The difference in all SCE rates between the baseline and intervention conditions was found to be significant at $p = 0.0539$ (statistic $S = 44.5$).

3.3.3.2 Analysis of Lane Change/Merge SCEs: Baseline Versus Intervention

After a careful evaluation of all SCEs included in the previous analysis, the research team determined that 18 SCEs in the baseline condition and 15 SCEs in the intervention condition were lane change/merge conflicts. The percentage of lane change/merge SCEs (16 percent; 33 lane change/merge SCEs/211 total SCEs) was in line with the crash estimates of VNTSC (13 percent) and IIHS (10 percent). Lane change/merge SCE rates per 10,000 mi (16,093km) were then calculated for each condition resulting in the following (see Figure 23):

- Baseline = 0.64 lane change/merge SCEs per 10,000 mi (16,093 km).
- Intervention = 0.34 lane change/merge SCEs per 10,000 mi (16,093 km).

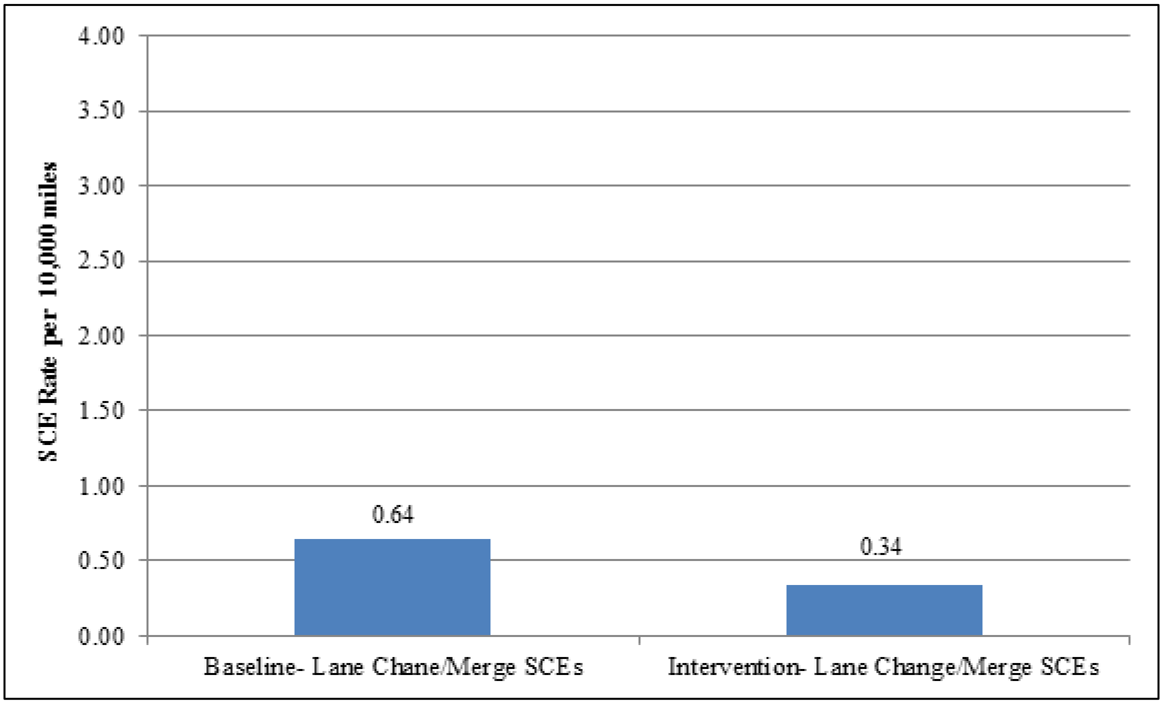

Figure 23. Bar chart. SCE rates for lane change/merge SCEs across baseline and intervention.

The research team calculated the difference in the lane change/merge SCE rates between the baseline and intervention conditions for each driver. The average difference in lane change/merge SCE rate was 0.37 SCEs per 10,000 miles (16,093km) (SE=0.20). Testing the results for normality indicated the distribution was normal (Shapiro-Wilk statistic $W = 0.91$, $p = 0.0818$). Therefore, a parametric statistical test was selected to analyze the data. The parametric test chosen was a paired t-test. The difference in lane change/merge SCE rates between the baseline and intervention conditions was found to be significant at $p = 0.0824$ (statistic $t = 1.85$). The intervention phase produced nearly half the SCE rate as compared to the baseline phase.

3.3.4 Qualitative Analysis (Driver and Manager Acceptance)

3.3.4.1 Driver Pre-study and Post-study Questionnaires

As previously mentioned, a sample of seven participants filled out pre- and post-study questionnaires (see Appendices B and C). The questionnaires had two purposes. The first was to determine driver baseline capability and comfort level (with no technological assistance system available) in performing lane change/merge maneuvers in different driving conditions (i.e., daytime, nighttime, clear weather, inclement weather). The second was to determine the participants' expectations of the BSW system before implementation, and their level of acceptance after experiencing the system in their vehicle for 4 months.

Table 7 contains results on the pre-study participant capability and comfort ratings with regard to lane change/merge maneuvers across various driving conditions. Overall, participants' mean ratings indicated that the levels of difficulty involved with 12 out of the 16 proposed scenarios were "neutral," "easy," or "very easy." The mean ratings for the four remaining scenarios rated as "difficult" were:

- Being aware of objects located in the area around the truck and trailer during daytime, inclement weather driving conditions.
- Merging into traffic during daytime, inclement weather driving conditions.
- Being aware of objects located in the area around the truck and trailer during nighttime, inclement weather driving conditions.
- Identifying what kind of vehicle is traveling in the adjacent lane during nighttime, inclement weather driving conditions.

Table 9. Pre-study participant capability and comfort level ratings with lane change/merge maneuvers in various driving conditions.

Question	Mean	Median	Standard Deviation	Rounded Mean Rating Result
During the day, how difficult is it to be aware of objects located in the area around your truck? This includes the blindspots (No-Zone) area. (1 [Extremely Difficult] to 7 [Extremely Easy])	4.36	4.00	0.75	Neutral
During the day, how difficult is it to tell what kind of vehicle is traveling in the lane beside you? (1 [Extremely Difficult] to 7 [Extremely Easy])	5.14	5.07	1.05	Easy
During the day, how difficult is it to merge into traffic? (1 [Extremely Difficult] to 7 [Extremely Easy])	4.14	4.00	0.93	Neutral
During the day, how confident are you that you will not hit an adjacent vehicle when merging into traffic? (1 [Extremely Unconfident] to 7 [Extremely Confident])	5.71	5.36	0.83	Very Confident

Question	Mean	Median	Standard Deviation	Rounded Mean Rating Result
During the day and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blindspots (No-Zone) area. (1 [Extremely Difficult] to 7 [Extremely Easy])	3.21	3.11	0.70	Difficult
During the day and when there is inclement weather, how difficult is it to tell what kind of vehicle is traveling in the lane beside you? (1 [Extremely Difficult] to 7 [Extremely Easy])	3.64	3.57	0.65	Neutral
During the day and when there is inclement weather, how difficult is it to merge into traffic? (1 [Extremely Difficult] to 7 [Extremely Easy])	3.21	3.11	0.70	Difficult
During the day and when there is inclement weather, how confident are you that you will not hit an adjacent vehicle when merging into traffic? (1 [Extremely Unconfident] to 7 [Extremely Confident])	5.00	5.00	0.71	Confident
At night, how difficult is it to be aware of objects located in the area around your truck and trailer when driving? This includes the blindspots (No-Zone) area. (1 [Extremely Difficult] to 7 [Extremely Easy])	4.14	4.07	0.78	Neutral
At night, how difficult is it to tell what kind of vehicle is traveling in the lane beside you? (1 [Extremely Difficult] to 7 [Extremely Easy])	3.57	3.79	0.47	Neutral
At night, how difficult is it to merge into traffic? (1 [Extremely Difficult] to 7 [Extremely Easy])	4.43	4.21	0.47	Neutral
At night, how confident are you that you will not hit an adjacent vehicle when merging into traffic? (1 [Extremely Unconfident] to 7 [Extremely Confident])	5.14	5.07	0.78	Confident
During the night and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blindspots (No-Zone) area. (1 [Extremely Difficult] to 7 [Extremely Easy])	3.29	3.14	0.66	Difficult
During the night and when there is inclement weather, how difficult is it to tell what kind of vehicle is traveling in the lane beside you? (1 [Extremely Difficult] to 7 [Extremely Easy])	3.21	3.11	0.61	Difficult

Question	Mean	Median	Standard Deviation	Rounded Mean Rating Result
At night and when there is inclement weather, how difficult is it to merge into traffic? (1 [Extremely Difficult] to 7 [Extremely Easy])	3.79	3.64	0.79	Neutral
At night and when there is inclement weather, how confident are you that you will not hit an adjacent vehicle when merging into traffic? (1 [Extremely Unconfident] to 7 [Extremely Confident])	4.71	5.00	0.83	Confident

The pre- and post-study questionnaires contained almost identical questions with regard to the BSW system performance that was expected and observed. Table 10 contains the ratings results from these questions in addition to results from statistical analyses comparing expectations before the BSW system was implemented to what was observed after 4 months of experiencing the BSW system. Wilcoxon Signed Rank tests were used to compare mean ratings for each pre- and post-study question. As the table shows, there were no statistically significant differences found between pre- and post-study mean ratings. These results indicate that, overall, participants' performance expectations of the BSW system before its implementation were met during the 4 months that it was installed and functional on their vehicles.

Table 10. Pre- to post-study BSW system comparison analyses.

Question	Pre-study Mean	Pre-study Median	Pre-study Standard Deviation	Post-study Mean	Post-study Median	Post-study Standard Deviation	Wilcoxon Signed Rank Test
How much do you like the idea of having a BSW system on your truck? (1 [Extremely Dislike It]–7 [Extremely Like It])	5.43	5.21	1.10	5.29	5.00	1.11	$p = 1.0$
I think the BSW system would/was... Useful–Useless (1–7, respectively)	2.00	1.50	1.24	2.79	2.50	1.60	$p = 0.50$
I think the BSW system would be/was... Pleasant–Unpleasant (1–7, respectively)	2.36	2.18	1.14	3.00	3.00	1.44	$p = 0.13$
I think the BSW system would be/was ... Bad–Good (1–7, respectively)	5.71	6.36	1.49	5.36	6.00	1.65	$p = 0.50$
I think the BSW system would be/was... Nice–Annoying (1–7, respectively)	3.00	3.50	1.42	3.00	3.00	1.83	$p = 0.75$
I think the BSW system would be/was... Effective–Excessive (1–7, respectively)	2.43	2.00	1.65	2.71	2.50	1.47	$p = 0.88$
I think the BSW system would be/was... Irritating–Likeable (1–7, respectively)	5.29	5.64	1.64	5.43	5.50	1.30	$p = 0.81$
I think the BSW system would be/was... Assisting–Worthless (1–7, respectively)	2.57	2.29	1.65	2.86	3.50	1.38	$p = 0.88$
I think the BSW system would be/was... Undesirable–Desirable (1–7, respectively)	5.21	5.61	1.58	5.43	5.00	1.10	$p = 0.53$
I think the BSW system would be/was... Raising Alertness–Sleep Inducing (1–7, respectively)	2.71	2.36	1.72	2.57	2.50	1.40	$p = 0.63$

The post-study questionnaire contained an additional eight rating scale questions regarding the BSW system's ease of use, effectiveness, and likeability. Table 11 contains the ratings results from these questions. Overall, the mean responses indicated that the BSW system helped improve driving performance, helped to eliminate blindspots, was easy to use, and glare from the visual warnings was comfortable (not disturbing). Participants did, however, rate the effectiveness of the BSW system's light (i.e., visual warning) during the day to be neutral.

Table 11. Post-study ratings on ease of use, effectiveness, and likeability.

Question	Mean	Median	Standard Deviation	Rounded Mean Rating Result
How does your driving performance with the BSW system compare to your driving performance without the BSW system? (1 [Extremely Worse] to 7 [Extremely Better])	5.14	5.00	1.07	Better
How much do you agree with the statement: "I would like to have the BSW system in my truck"? (1 [Strongly Disagree] to 7 [Strongly Agree])	5.43	6.00	1.51	Somewhat Agree
How much do you agree with the statement: "BSW system eliminates the blindspots around my truck"? (1 [Strongly Disagree] to 7 [Strongly Agree])	5.29	6.00	1.70	Somewhat Agree
How much do you agree with the statement: "BSW system is easy to use"? (1 [Strongly Disagree] to 7 [Strongly Agree])	5.86	6.00	0.90	Agree
How uncomfortable is the glare from the BSW system light when you are driving at night and looking forward down the road? (1 [Extremely Uncomfortable] to 7 [Extremely Comfortable])	4.86	5.00	1.21	Comfortable
How uncomfortable is the glare from the BSW system light when you are driving at night and looking directly at the light? (1 [Extremely Uncomfortable] to 7 [Extremely Comfortable])	4.57	4.00	1.13	Comfortable
How effective is the BSW system light when you are driving during the day and looking forward down the road? (1 [Extremely Effective] to 7 [Extremely Ineffective])	3.64	4.00	1.25	Neutral
How effective is the BSW system light when you are driving during the day and looking directly at the light? (1 [Extremely Effective] to 7 [Extremely Ineffective])	3.64	3.00	1.49	Neutral

Prior to the field study, participants were asked to write down two things they thought they would like about the BSW system, and two things they thought they would dislike about the system. Not all participants provided two responses per question. Participant responses to items they thought they would like or dislike can be found in Table 12 and Table 13, respectively.

Table 12. Participant open-ended responses to the question, "What are two things you think you will like about BSW system?"

Response
Alert me to a situation I may not see.
It's possible that it may work well in some conditions.
Helping alert drivers of danger.
The ability to help me detect other vehicles in my blindspots.
Helps you when you can't see small cars in the mirrors.
Make me a safer driver.
It could also be another way of detecting a vehicle in a blindspot that you otherwise may not see.
Helps to see situation to make awareness that all accidents are not the drivers fault.

Table 13. Participant open-ended responses to the question, "What are two things you think you will dislike about BSW system?"

Responses
Another pre-trip check (minor).
Could be a distraction.
I don't have any dislikes about them.
May not work well at all.

On the post-study questionnaire, participants were asked to write down two things they liked about the BSW system and two things they disliked about the system. Not all participants provided two responses per question. Participant responses to items they liked and disliked can be found in Table 14 and Table 15, respectively.

Table 14. Participant open-ended responses to the question, "What are two things you liked about BSW system?"

Responses
Alerts you to blind drivers.
One thing is that it works pretty well in any condition.
The camera and recorder so you could give voice feedback.
I like how the lights work to help detect vehicles in my blindspots.
Useful in bad weather.
Side Eyes—indicators.
Very helpful during driving day or night.
Peace of mind.
I like how easy the system was to use.

Table 15. Participant open-ended responses to the question, "What are two things you disliked about BSW system?"

Responses
Too many false positives.
Light comes on when no cars around.
Light comes on when you are beside inanimate objects.
The mirror lights at night would sometimes go off for no reason sometimes.
I didn't like how the passenger-side light was somewhat ineffective during the day.
It's a good system; I think it's helpful.
Light brightness—fixed with tape was fine.
Need to attenuate response.
Could be improved so that light does not come on beside inanimate objects.
The camera, cause it caught you doing something stupid like eating.
I didn't like that the lights went a little crazy during rain showers. It was like they were confused.

When asked if the participant was comfortable using the BSW system to its full extent within the first month, six participants responded "yes," while one participant responded "no." In addition, when asked about whether their opinions of the BSW system changed during participation, the responses were mixed with two negative and five positive comments (see Table 16).

Table 16. Participant open-ended responses to the question, "Did your opinion about the system change during your participation in the study?"

Responses
Always on—Always Looking—Too many false positives.
No, not a lot of help.
No, I thought that from the start that it would be very helpful during driving.
Thought that the equipment would be somewhat in the way or you would have to be really careful but almost all of the equipment was out of the way.
No, I thought it was helpful throughout the study.
Useful.
Help out to let us know where cars are at coming around us.

3.3.4.2 Fleet Manager Interviews

Two fleet managers were recruited to participate in a post-study interview in order to identify any safety benefits the fleet may have recognized from the BSW system, the overall fleet's acceptance of the system, positives and negatives in system implementation within the fleet, and economic issues with regard to technology implementation within the fleet. Of the two participants, only one agreed to participate in the post-study interview.

The participating manager believed that the BSW system would change drivers' on-road driving because it would notify them of objects or vehicles in their blindspots. When asked how a fleet might go about measuring whether the BSW system was effective, the manager suggested that close monitoring of more or less damage to the vehicles would be a good indicator; more specifically, damage that is commonly associated with lane change/merge incidents. The manager indicated that the fleet currently provides a broad range of driver training (e.g., new driver training, fuel economy training, Smith System), and that the introduction of the BSW system would not drastically affect the training currently in place. The participating fleet is actively pursuing aftermarket safety technologies for implementation in their trucks. For example, many trucks have PeopleNet, SmartDrive, and roll stability systems. Initially, it is common for drivers to be unaccepting of new technologies; however, they often realize their benefits after using them in a real-world scenario.

When asked about other features that the manager would want to see in the system, it was indicated that smaller lights on the mirrors might be implemented as several of the drivers complained about the visual warnings being too bright. The manager was also concerned about the BSW system installation procedures. More specifically, brackets for the system were not customized for trucks, resulting in longer truck downtime during installation. Additionally, there was some exposed wiring that was evident after installations were complete.

The manager indicated that most of the incidents that occur within the fleet are to the front and rear of their vehicles (not as many to the sides). A primary factor for implementing new technologies is return on investment (ROI) estimates provided by the technology vendor. The manager was uncertain as to whether the additional cost of purchasing the BSW system for the fleet would be economically justified. The manager did indicate that federal or insurance incentives would indeed influence decisions on adoption of the BSW system. Overall, the manager believed that the BSW system would be useful in the fleet.

3.3.5 Blindspot Warning System's Accuracy Assessment

Reductionists successfully reduced 209 weeks of driver intervention data, resulting in approximately 1,760 mi (2,832 km) of both daytime and nighttime driving. In total, 3,530 random time syncs were evaluated over the 1,760 mi (2,832 km). The BSW system performance results will be presented by vehicle side (driver-side, passenger-side) in separate sections below.

3.3.5.1 Driver-side

During the driver-side BSW system performance reduction, 330 vehicles or objects were determined to be in the detection zone. Of the 330 instances, 298 were correctly detected (Table 17). Therefore, the estimated probability of the system correctly detecting a vehicle or object in the BSW system driver-side detection zone was 90.30 percent, P(hit) = 298/330 = 0.90. The large majority of the missed detections observed (24 of the 32 total) were not of vehicles, but rather objects labeled as "guardrails/barriers" positioned off of the roadway. Other missed detections consisted of seven "cars," and one object labeled as "other stationary object."

Table 17. Detection paradigm results for the driver-side BSW system performance in field study.

Light Activation	In Zone	Not in Zone
Yes	298	188
No	32	3012

During the driver-side BSW system performance reduction, 3,200 samples resulted in no vehicles or objects present in the driver-side detection zone. Of the 3,200 instances, 3,012 were correctly rejected (Table 18). Therefore, the estimated probability of the system correctly rejecting a vehicle or object outside the BSW system driver-side detection zone was 94.13 percent, P(hit) = 3,012/3,200 = 0.94. The false alarms observed were attributed to the nearest vehicle or object in the detection zone (if any). Table 18 presents a list of the nearest vehicles or objects attributed to the false alarms and their corresponding counts.

Table 18. Counts of vehicles and objects attributed to false alarms for the driver-side.

Description	Count
Other Stationary Object	3
Van	6
Heavy Truck	7
Sign	7
Pickup Truck	8
SUV	8
Fence	11
Car	25
Guardrail/Barrier	29
None	85

3.3.5.2 Passenger-side

During the passenger-side BSW system performance reduction, 439 vehicles or objects were determined to be in the detection zone. Of the 439 instances, 404 were correctly detected (Table 19). Therefore, the estimated probability of the system correctly detecting a vehicle or object in the BSW system passenger-side detection zone was 92.03 percent, P(hit) = 404/439 = 0.92. The large majority of the missed detections observed (32 of the 35 total) were not of vehicles, but rather objects labeled as “guardrails/barriers” positioned off of the roadway. Other missed detections consisted of one “hill/embankment/cliff,” one object labeled as “other stationary object,” and one “sign.”

Table 19. Detection paradigm results for the passenger-side BSW system performance in field study.

Light Activation	In Zone	Not in Zone
Yes	404	158
No	35	2933

During the passenger-side BSW system performance reduction, 3,091 samples resulted in no vehicles or objects present in the detection zone. Of the 3,091 instances, 2,933 were correctly rejected (Table 20). Therefore, the estimated probability of the system correctly rejecting a vehicle or object outside the BSW system passenger-side detection zone was 94.89 percent, P(hit) = 2933/3091 = 0.95. The false alarms observed were attributed to the nearest vehicle or object in the detection zone (if any). Table 20 presents a list of the nearest vehicles or objects attributed to the false alarms and their corresponding counts.

Table 20. Counts of vehicles and objects attributed to false alarms for the passenger-side.

Object Description	Count
Pickup truck	1
Van	1
Parked Vehicle	3
SUV	3
Heavy Truck	6
Car	8
Hill/Embankment/Cliff	12
Sign	13
Other Stationary Object	17
Guardrail/Barrier	39
None	52

3.3.6 Fleet-owned Data Exploratory Analysis

Fleet-owned data were collected from the participating motor carrier for each driver for the 4 months leading up to the activation of the BSW system and the 4 months after activation of the BSW system. The purpose of collecting the fleet-owned data was so that the research team could investigate its potential in evaluating the safety impact of the BSW system.

Upon receipt of the data from the fleet, a total of nine incidents were identified (three in baseline, six in intervention). These incidents occurred over 1,458,248 mi (2,346,823 km) of driving (763,340 mi [1,228,477 km] in baseline, 694,908 mi [1,118,346 km] in intervention). These events were described as follows:

- Baseline.
  - Truck struck a mailbox while backing.
    - Preventable = Yes.
  - While entering a customer’s drive, tandems struck decorative landscaping.
    - Preventable = Yes.
  - Truck ran over a recap tread in roadway at night.
    - Preventable = No.
- Intervention.
  - Truck struck curb and guardrail going through a toll booth.
    - Preventable = Yes.
  - While backing, truck struck front bumper on a fixed object.
    - Preventable = Yes.
  - Truck was pulling forward and trailer door struck a fixed object breaking door hinges.
    - Preventable = Yes.

- Truck struck a pothole on bridge breaking bumper.
  - Preventable = Yes.
- Other vehicle blew a tire and the tire struck the truck.
  - Preventable = No.
- Truck was struck by other vehicle's mirror while other vehicle was turning.
  - Preventable = No.

Similar to the SCE analyses previously described, baseline and intervention incident rates were calculated per 10,000 mi (16,093 km):

- Baseline = 0.04 incidents per 10,000 mi (16,093 km).
- Intervention = 0.09 incidents per 10,000 mi (16,093 km).

The average difference in baseline and intervention incident rates across all drivers was -0.036 per 10,000 mi (16,093 km) (the negative value indicates that the intervention incident rates were higher, on average, than the baseline incident rates) (SE = 0.05). A non-parametric statistical test, the Wilcoxon Signed Rank test, was selected to compare the drivers' differences in baseline to intervention incident rates. The resulting statistic and p-value from the Wilcoxon Signed Rank test were $S = -2.00$ and $p = 0.8125$, respectively. These results indicate that the difference in baseline to intervention rates could not be found to be significantly different from each other. In the fleet data sample, there was not a statistically significant difference in safety performance between the two test conditions.

4. CONCLUSIONS

When it comes to driving large CMVs, visibility around the vehicle is extremely important. The size (up to 102 inches [259.08 cm] wide and sometimes more than 70 ft [21.34 m] long) and configuration (various load dimensions) of the CMV presents many challenges for the driver to see around the vehicle adequately. The vehicle characteristics can create large blindspots (Figure 5) that can hide adjacent vehicles and objects from the driver's sight. The tested BSW system provides a novel (i.e., uses infrared, laser-based sensors) approach to detecting objects within the equipped truck's blindspot areas. This study systematically exercised the system under various operational scenarios to understand its abilities and limitations. These abilities and limitations and their effects on driver performance are discussed in this chapter.

4.1 SYSTEM PERFORMANCE

The subject BSW system's performance was measured based on its operational envelope and its ability to detect vehicles of various sizes under varying environmental conditions. As mentioned, this performance was tested initially under controlled experimental conditions and then evaluated under real-world driving conditions within a commercial fleet.

The effectiveness of any blindspot detection system depends on the boundaries of its operational envelope (or detection zone). This detection zone must be properly positioned relative to the vehicle and appropriately sized to capture true threats (i.e., passing traffic). If, for instance, the detection zone is positioned in a visible area (as opposed to a blindspot area) around the truck, the driver would receive redundant information and the driver's impression of the system's value could potentially be diminished. Also, a detection zone that is too large would detect objects beyond the immediate proximity to the subject vehicle's path—which would be irrelevant to the safety of the driver and vehicle—creating potential false alarms and lowering the driver's general impression of the technology. If the detection zone is too small, then objects that are relevant to the safety of the driver and the vehicle could be missed.

The object detection zone mapping conducted during the quasi-static testing indicated that the BSW system provided important coverage on the passenger-side blindspots directly adjacent to the tractor and front third of the trailer. Also, by adding an additional forward-looking sensor, the BSW system addressed a large blindspot area created by drivers looking over the passenger-side of the hood.

Two areas were discovered where coverage by the BSW system could be improved. The driver-side BSW system unit leaves an area directly adjacent to the tractor uncovered for high-sitting, eye-height positions. This uncovered area is large enough to fit a small vehicle such as a motorcycle. On both the driver- and passenger-sides, the BSW system detection zones do not provide coverage for the rear two-thirds of the trailer for about half of the adjacent lanes (an area where the FOV for flat mirrors is limited). CMV drivers tend to rely on flat mirrors to spot adjacent vehicles and to perceive their associated speeds. Convex mirrors provide a minified view around the vehicle and some drivers prefer the use of planar mirrors for quickly spotting adjacent traffic and for perceiving a vehicle's oncoming speed.

Another key attribute of a blindspot detection system is the ability to sense vehicles of varying sizes under varying environmental conditions. Results from the quasi-static testing showed that the BSW system performed well at accurately detecting smaller light vehicles as well as motorcycles and performed equally well at accurately rejecting light vehicles of different types and sizes when they were not in the detection zone. During passing and merging testing on the Smart Road, the BSW system performed suitably in detecting light vehicles of different types and sizes under varying conditions (multiple vehicles present, rain, and varying light-vehicle approach scenarios). Two conditions were found that seemed to create difficulties for the BSW system, namely, rain spray from the equipped vehicle's tires and small vehicle approach angles that most likely resulted from positioning the vehicle between the BSW system's laser beams.

The performance evaluation method used for assessing the accuracy of the BSW system's object detection during the field study resulted in a 90.3 percent correct detection rate for the driver side and a 92.03 percent correct detection rate for the passenger side. The large majority of the missed detections observed were not of vehicles, but of objects labeled as "guardrails/barriers" positioned off of the roadway. It is important to note that the reduction performed for determining the BSW system relied on subjective analysis determined through watching video samples. It is possible that some of the missed detections identified were indeed out of the BSW system detection zone. The performance evaluation also showed that a correct rejection rate of 94.13 percent was found for the driver-side (5.87 percent false alarm rate), and a 94.89 percent correct rejection rate was found for the passenger-side (5.11 percent false alarm rate). The high correct rejection rates are indicative of a well-designed BSW system. The false alarms found were attributed to the nearest vehicle or object (if any) in the detection zone. The most common attributes found were "none" and/or "guardrail/barrier." This finding highlights a gap between the tested system's capability to detect objects in the field of range and drivers' expectation that certain true objects detected in these zones should not be indicated on the LEDs. Therefore, drivers appear to expect not only blindspot object detection but also classification and suppression of certain types of objects from such a system.

The BSW system was also prone to detecting the CUT trailer during low-speed turning maneuvers ($\geq$ 151 degrees during left turns, and $\geq$ 137 degrees during right turns). It is recommended during BSW system training with CUT drivers that vendor's technicians and/or fleet managers describe the system's performance during turning maneuvers so that drivers are aware that maneuvers such as extreme articulations generate BSW system activations. Again, this finding appears to be an improvement to other BSW systems such as radar-based technology. The results of the IVBSS Heavy Truck FOT final report stated that more than 50 percent of side-hazard alerts were issued with no targets present in adjacent lanes. According to the IVBSS authors, many of these false alarms were attributed to reflections from the trailer body articulations for double-trailer configurations at highway speeds.(27)

4.2 POTENTIAL SAFETY BENEFITS

The potential safety benefits were determined by evaluating whether the operator's driving behavior, as measured by the rate of involvement in SCEs, changed when the BSW system was introduced. To be effective, a blindspot detection system should improve drivers' lane change/merge behaviors and possibly improve their overall safety driving performance.

The safety benefit analyses using SCEs resulted in potential safety benefits for both analyses performed (analysis of all SCE rates between baseline and intervention, and an analysis of lane change/merge SCE rates between baseline and intervention) with resulting *p* values of 0.0539 and 0.0824, respectively.

In addition to the data extracted directly from the BSW system evaluation, the research team requested fleet-owned safety data; however, this analysis did not find a safety benefit from the BSW system. This was most likely due to the low number of incidents reported over the many miles of data collected. During the safety evaluation portion of the study, SCEs were used to evaluate conflicts (not all of which were actual crashes involving property damage). Crashes and incidents resulting in property damage are indeed rare, which is why SCEs can be a useful surrogate measure of risky driving and the behaviors that lead to them. The use of fleet data to evaluate safety systems most likely requires that more elaborate measures are collected before true safety benefits can be determined.

4.3 USER ACCEPTANCE

An investigation of drivers' opinions on the BSW system's performance during normal driving revealed the following:

- The responses from the seven participants surveyed concurred with the findings of the safety benefits analyses performed by the research team. Overall, participants' performance expectations of the BSW system before its implementation were met during the 4 months that it was installed and functional on their vehicles. Their mean responses indicated that the system helped improve driving performance, helped to eliminate blindspots, was easy to use, and glare from the visual warnings was comfortable. In addition, six of the seven participants became comfortable using the BSW system to its full extent within the first month. All of the results indicate an acceptance of the BSW system by the participants surveyed in the field study.

- The fleet manager indicated that the participants responded positively to the implementation of the BSW system. Overall, the manager believed that the BSW system would be useful in improving safety within their fleet.

4.4 STUDY LIMITATIONS

The following limitations should be considered when assessing the results of this study:

- A total 1,338,818 mi (2,154,618 km) collected were reduced to 722,639 mi (1,162,974 km) for SCE analysis due to driver attrition, equipment issues, and fleet vehicle availability (i.e., tractor-trailers returned to terminal from trips sporadically). This reduction in valid data available for analysis most likely resulted in some SCEs not being identified.

- As previously mentioned, the participating fleet actively pursues aftermarket technologies for implementation in their trucks. During this study, a small number of fleet-owned technologies were present in participants’ vehicles. The research team did not have control over what other technologies were included in the participants’ vehicles, and therefore cannot be completely certain of the level of influence (if any) they had on overall driver performance.

- There is a potential that seasonality (e.g., road conditions, length of day) could have affected the SCE rates measured in the baseline (which occurred in late fall through the winter) as compared to the intervention (which occurred from late winter into spring). Although a somewhat equal number of SCEs between conditions occurred in inclement weather (five in baseline, four in intervention), driver behavior may change based on season and, therefore, should be considered when interpreting the results of the field study.

The BSW system performance evaluation method used during the field study analysis was subjective due to the fact that data reductionists, although trained by senior research staff on proper techniques for distance approximations, used video to determine if vehicles were in the detection zone.

5. RECOMMENDATIONS

The BSW system tested provides benefits to drivers by increasing their awareness of vehicles in adjacent lanes; however, the findings of the study also indicate that there are opportunities to further improve overall BSW system performance. The following are offered as potential design improvement recommendations based on the findings of this evaluation that could be applicable for all BSW systems. It should be noted that these recommendations are based on data collected using CUTs and may not be easily transferred to other modes of transportation without further investigation.

- Participating drivers indicated that the system could be greatly improved by further reducing the false alarms (as perceived by the operators) that occur. In fact, the majority of the system improvement comments provided by drivers were related to false alarm conditions. Understandably, BSW systems appear to have a propensity to activate on inanimate objects (e.g., guardrails, barriers/fences, and signs); however, drivers perceive these as false alarms since relevant objects such as vehicles are not present. Efforts should be made to refine the sensors' performance by further attempting to classify detected objects in the blindspots in relation to their relevance to given driving conditions and suppressing those that drivers perceive as false alarms.
- The other area of improvement voiced by drivers was related to the brightness of the visual warning. During the daytime, several drivers commented that the passenger-side LEDs were not effective due to low brightness and distance from the driver. Conversely, some drivers were covering the LEDs on both sides to reduce the brightness during nighttime conditions. It is suggested that the LED brightness levels be adjusted or adjustable to appropriate levels based on ambient light conditions and distance from the driver. SAE J2802[28] and ISO FDIS 17387[29] specifications provide further guidance on designing brightness (i.e. luminance) levels. While these standards are intended for passenger vehicles (and not CMVs), the recommended luminance levels may provide system developers insight into appropriate luminance levels that could be used for such BSW systems. Regardless of the source, it is recommended that the luminance levels under varying ambient light conditions (e.g., day and night) be tested and verified for appropriateness for the intended uses.
- Although the BSW system provided important coverage of passenger-side blindspots, there were two areas of coverage that could be improved. The first is the driver-side adjacent to the tractor. The detection zone should be expanded forward to cover blindspot areas as indicated in Figure 11, Figure 12, and Figure 13. This is especially important for detecting small vehicles such as motorcycles. It is also suggested, based on established blindspot detection functional goals and requirements,[30] that additional BSW system sensors along the side of the trailer would likely improve the useful detection coverage to the areas along both sides of the entire trailer's length. This additional coverage along the trailer would not be essential to the core performance of the blindspot detection system since drivers have indirect vision coverage from the vehicle's mirrors. However, it could be beneficial to the driver in high-density or fast-moving traffic.
- Another area of improvement suggested by the authors is the indication of a system failure. BSW systems should have the clear means to communicate to the user when the

complete system is not fully functional. Currently, the evaluated BSW system flashes the amber LEDs at specific frequencies to indicate various system failure modes. However, there is no means of communicating to the driver that the amber LEDs are not working properly. Since the non-lit LEDs indicate a safe condition during a lane change or merge, a failure of the LEDs could lead to a conflict with an adjacent vehicle. It is recommended that some signal be provided that indicates when the actual LEDs have failed.

All of the above suggestions would need to be evaluated by the system developers and engineers for feasibility and success under their system's actual operational conditions.

Further, a BSW system's perceived performance appears closely tied to its warning mechanism. Additional research on best methods to convey BSW messages to the driver would be beneficial.

APPENDIX A—VENDOR SOLICITATION WEBSITE

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FMCSA's Advanced System Testing utilizing Data Acquisition System Highway (FAST DASH) Program

Does your company have a promising commercial vehicle safety technology that could be independently evaluated by VTTI?

The safety objective of the Federal Motor Carrier Safety Administration (FMCSA) is to save lives and reduce injuries by preventing and minimizing the severity of truck and bus crashes (FMCSA, 2010). According to the FMCSA, the development, evaluation, and deployment of advanced safety technology will be a key to realizing this objective.

Currently, there are numerous safety systems in development that have the potential to significantly reduce crashes on our nation's roadways. For a variety of reasons, however, including lack of supporting tests and evaluations, the potential benefits that these systems may provide in reducing crashes may never be realized. The FMCSA envisions, through cooperation with the commercial vehicle (CV) industry, an influx of CV safety technologies that support the expanding role of the CV industry to safely, securely, and efficiently transport the nation's goods, products, and people. Information from motor carriers and other organizations about the effectiveness of these systems in improving safety will be valuable in advancing their further use in the CV industry.

The objective of the FMCSA's Advanced System Testing utilizing Data Acquisition System Highway (FAST DASH) program is to perform quick turn-around independent evaluations of promising safety technologies aimed at commercial vehicle operations (CVO). The goal of the FAST DASH program is to determine the efficacy of the safety system using the following high–level metrics:

- Crash reduction effectiveness (i.e., safety improvements)
- Unintended consequences (i.e., safety disbenefits)
- User (e.g., driver, safety manager) acceptance (i.e., subjective opinions)

The Virginia Tech Transportation Institute (VTTI) has been contracted to conduct the independent evaluations and the focus is to evaluate market–ready safety systems. At this time, VTTI is accepting applications from those interested in having their promising CV safety technology independently evaluated.

If interested, please send Darrell Bowman (Program Lead) at dbowman@vtti.vt.edu **by 5:00 PM on November 30, 2010** a brief (less than 250 words) system description as well as a list of commercial carriers who currently employ the safety technology in their fleet. Please note the selected technology vendor will be responsible for providing, free of charge, as many safety systems needed to conduct the evaluation. All interested applicants should read the research project outline in the Statement of Work (SOW). A copy of the SOW can be downloaded below. Interested technology vendors should submit a brief, three–page proposal on how they will address the tasks outlined in the SOW. Proposals and questions should be sent to dbowman@vtti.vt.edu. Vendors are encouraged to submit proposals on an ongoing basis and they will be placed in a pipeline of promising projects under continuous consideration but only those that are submitted **by 5:00 p.m. Eastern Time (ET) on December 8, 2010** will be considered for the upcoming 2011 technology evaluation selection.

Statement Of Work For System Provider (11-30-2010)
Clarifications to Statement Of Work (11-30-2010)

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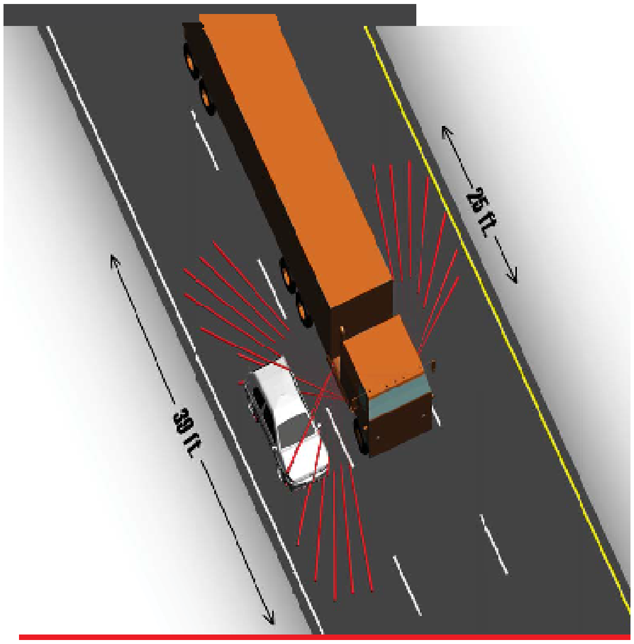
APPENDIX B—SIDEEYES QUICK START GUIDE



How SideEyes® Works

The SideEyes® system uses an array of 7 to 14 lasers to create a 3-D detection zone 39-feet-long on passenger side and 25-feet-long on driver side – your side NO ZONES. It detects vehicles in the main mirror's blind area on long-haul, over-the-road interstate driving. When on a two-lane road, expect SideEyes® to detect trees and other roadside objects that pass through the NO ZONE. When objects enter the NO ZONE areas, you will be alerted by an amber LED Indicator mounted on your driver and passenger side mirrors.

Your good driving and SideEyes® technology work together – and you will reduce accidents.

***Power-on bulb check** – Indicators will flash rapidly for a few seconds each time you power on the system.*

***Rain & fog** – System may detect heavy mist or dense fog during poor driving conditions; use extra vigilance while driving in these conditions.*

***Two-second delay** – Indicator remains on 2 seconds after an object exits zone.*

***Night dimmer** – Indicator will self-dim at night.*

SideEyes® Units Test Themselves

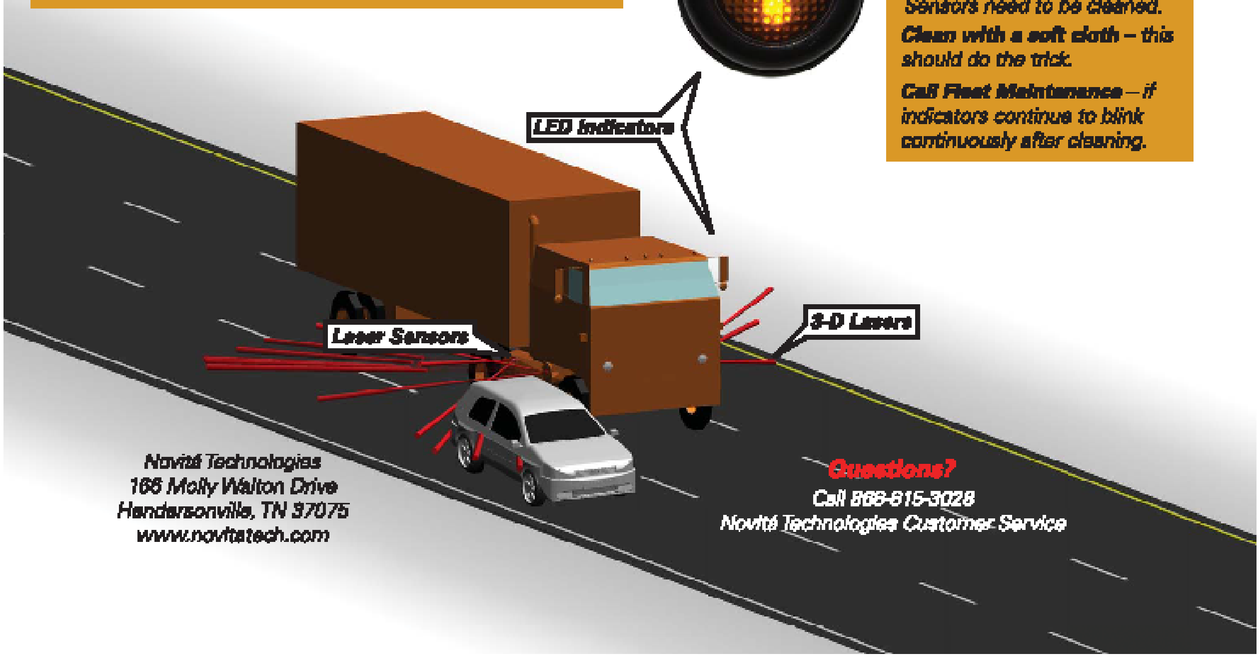
*If alert lights blink randomly, the system is warning you something might need adjustment. If this happens, the system is not working accurately. **Call Fleet Maintenance for assistance.***

Is SideEyes® Dirty?

If the LED indicators blink continuously, SideEyes® Laser Sensors need to be cleaned.

***Clean with a soft cloth** – this should do the trick.*

***Call Fleet Maintenance** – if indicators continue to blink continuously after cleaning.*



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Questions?
Call 866-615-3028
Novitá Technologies Customer Service

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APPENDIX C—PRE-STUDY QUESTIONNAIRE

Pre-Study Questionnaire

Instructions

Please answer the following questions by writing a number from the scale below them that best matches your response. Please write your answer on the line following the word “Response” as shown below.

Response: __4___

Half numbers such as 4.5 are allowed.

Day Time Driving

1. **During the day, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind-spots (no-zone) area.**

   Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

2. **During the day, how difficult is it to tell what kind of vehicle is traveling in the lane beside you?**

   Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

3. **During the day, how difficult is it to merge into traffic?**

   Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

4. **During the day, how confident are you that you will not hit an adjacent vehicle when merging into traffic?**

Response: _________

1	2	3	4	5	6	7
Extremely Unconfident	Very Unconfident	Unconfident	Neutral	Confident	Very Confident	Extremely Confident

Day Time Inclement Weather Driving

5. **During the day and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind-spots (no-zone) area.**

Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

6. **During the day and when there is inclement weather, how difficult is it to tell what kind of vehicle is traveling in the lane beside you?**

Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

7. **During the day and when there is inclement weather, how difficult is it to merge into traffic?**

Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

8. **During the day and when there is inclement weather, how confident are you that you will not hit an adjacent vehicle when merging into traffic?**

Response: _________

1	2	3	4	5	6	7
Extremely Unconfident	Very Unconfident	Unconfident	Neutral	Confident	Very Confident	Extremely Confident

<u>Night Time Driving</u>

9. **At night, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind-spots (no-zone) area.**

Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

10. **At night, how difficult is it to tell what kind of vehicle is traveling in the lane beside you?**

Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

11. **At night, how difficult is it to merge into traffic?**

Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

12. **At night, how confident are you that you will not hit an adjacent vehicle when merging into traffic?**

    Response: _________

1	2	3	4	5	6	7
Extremely Unconfident	Very Unconfident	Unconfident	Neutral	Confident	Very Confident	Extremely Confident

<u>Night Time Inclement Weather Driving</u>

13. **During the night and when there is inclement weather, how difficult is it to be aware of objects located in the area around your truck and trailer while driving? This includes the blind-spots (no-zone) area.**

    Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

14. **During the night and when there is inclement weather, how difficult is it to tell what kind of vehicle is traveling in the lane beside you?**

    Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

15. **At night and when there is inclement weather, how difficult is it to merge into traffic?**

    Response: _________

1	2	3	4	5	6	7
Extremely Difficult	Very Difficult	Difficult	Neutral	Easy	Very Easy	Extremely Easy

16. At night and when there is inclement weather, how confident are you that you will not hit an adjacent vehicle when merging into traffic?

Response: _________

1	2	3	4	5	6	7
Extremely Unconfident	Very Unconfident	Unconfident	Neutral	Confident	Very Confident	Extremely Confident

Background

SideEyes® is a blind-spot detection system that uses an array of 7 to 15 lasers to create a three-dimensional detection zone on both the driver- and passenger-sides of the commercial vehicle. The driver is alerted to a vehicle in the blindspot via amber LEDs mounted on both the left and right side-view mirrors. This system will provide drivers with information not available with conventional mirrors to make better decisions regarding lane changes and merges.

1) How much do you like the idea of having a SideEyes® System on your truck? (Please place an X on each line below that best matches your response)

1	2	3	4	5	6	7
Extremely Dislike It	Very Much Dislike It	Dislike It	Neutral	Like It	Very Much Like It	Extremely Like It

2) I think SideEyes® would be…

	1	2	3	4	5	6	7	
useful								useless
pleasant								unpleasant

	1	2	3	4	5	6	7	
bad	1	2	3	4	5	6	7	good
nice	1	2	3	4	5	6	7	annoying
effective	1	2	3	4	5	6	7	excessive
irritating	1	2	3	4	5	6	7	likeable
assisting	1	2	3	4	5	6	7	worthless
undesirable	1	2	3	4	5	6	7	desirable
raising alertness	1	2	3	4	5	6	7	sleep-inducing

3) What are two things you think you will like about SideEyes®?

1. ____

2. ____

4) What are two things you think you will dislike about SideEyes®?

1. ____

2. ____

APPENDIX D—POST-STUDY QUESTIONNAIRE

Post-Study Questionnaire

<u>Instructions</u>

Please answer the following questions by writing a number from the scale below them that best matches your response. Please write your answer on the line following the word "Response" as shown below.

Response: __4___

Half numbers such as 4.5 are allowed.

1) How much do you like the idea of having a SideEyes® System on your truck?

Response: _________

1	2	3	4	5	6	7
Extremely Dislike It	Very Much Dislike It	Dislike It	Neutral	Like It	Very Much Like It	Extremely Like It

2) I think the SideEyes® is… (Please place an X on each line below that best matches your response)

	1	2	3	4	5	6	7	
useful	1	2	3	4	5	6	7	useless
pleasant	1	2	3	4	5	6	7	unpleasant
bad	1	2	3	4	5	6	7	good
nice	1	2	3	4	5	6	7	annoying
effective	1	2	3	4	5	6	7	excessive

irritating 1 2 3 4 5 6 7 likeable

assisting 1 2 3 4 5 6 7 worthless

undesirable 1 2 3 4 5 6 7 desirable

raising alertness 1 2 3 4 5 6 7 sleep-inducing

3) How does your driving performance with SideEyes® compare to your driving performance without SideEyes®?

Response: _________

1	2	3	4	5	6	7
Extremely Worse	Much Worse	Worse	Neutral	Better	Much Better	Extremely Better

4) How much do you agree with the statement: "I would like to have SideEyes® in my truck."

Response: _________

1	2	3	4	5	6	7
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

5) How much do you agree with the statement: "SideEyes® eliminates the blind-spots around my truck."

Response: _________

1	2	3	4	5	6	7
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

6) How much do you agree with the statement: "SideEyes® is easy to use."

Response: _________

1	2	3	4	5	6	7
Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree

7) How uncomfortable is the glare from the SideEyes® light when you are driving at night and looking forward down the road?

Response: _________

1	2	3	4	5	6	7
Extremely Uncomfortable	Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable	Extremely Comfortable

8) How uncomfortable is the glare from the SideEyes® light when you are driving at night and looking directly at the light?

Response: _________

1	2	3	4	5	6	7
Extremely Uncomfortable	Very Uncomfortable	Uncomfortable	Neutral	Comfortable	Very Comfortable	Extremely Comfortable

9) How effective is the SideEyes® light when you are driving during the day and looking forward down the road?

Response: _________

1	2	3	4	5	6	7
Extremely Effective	Very Effective	Effective	Neutral	Ineffective	Very Ineffective	Extremely Ineffective

10) How effective is the SideEyes® light when you are driving during the day and looking directly at the light?

Response: _________

1	2	3	4	5	6	7
Extremely Effective	Very Effective	Effective	Neutral	Ineffective	Very Ineffective	Extremely Ineffective

11) Were you comfortable using the system to its full extent within the first month?

YES (if yes, skip to 13) **NO** (if no, answer 12)

12) How long did it take you to become comfortable using the system to its full extent?

____

____

13) Did your opinion about the system change during your participation in the study? (Please explain)

____

____

____

____

____

14) What are two ***things you like about*** the system, and why?

1. ____

2. ____

15) What are two ***things you dislike about*** the system, and why?

1. ____

2. ____

<u>Additional Comments</u>

Are there any additional comments you would like to make regarding the system?

1. ____

2. ____

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APPENDIX E—FLEET MANAGER INTERVIEW QUESTIONS

Fleet Manager Interview

Safety Benefits

1. Do you think drivers using a SideEyes® system would change their on-road driving?
    1. If yes: why/in what ways?
    2. If no: why?
2. Do you think having SideEyes® would change how drivers drive at terminals and other loading/unloading points?
3. What types of routes does your company primarily operate? (***IF company runs different route types***) Would a SideEyes® System help local/regional, line, and long haul drivers differently?
    1. If so, why
    2. If not, why?
4. If the SideEyes® system was being tested in revenue generating runs, what would tell you that it was working well?
    1. What would tell you that it wasn't working well?

Company/Driver Acceptance

5. Does your company offer or give any type of training to CDL drivers?
    1. If so, please briefly describe. (e.g., new driver training, fuel economy training, etc.)
    2. (***IF company offers driver training***) Would the SideEyes® technology change driver training within your company.
        1. If so, how?
6. What do you think drivers' initial reaction to SideEyes® was?
7. Has your company previously implemented any aftermarket safety technologies?
    1. If so, which ones?
    2. How have drivers reacted to each?
    3. What safety benefits of these technologies have you experienced?

Fleet Implementation

8. Are there any other features you would want to see in this device?
    a. If yes, what are they? Why?
    b. How much additional cost per unit would your company be willing to pay for this/these features?
9. What maintenance concerns do you have regarding this system?

Economic Issues

10. If possible, could you please estimate the costs associated with lane change/merge crashes incurred each year by:

    1. Your terminal?
    2. Your company?
11. How much would you be willing to pay for this system in your fleet per truck?
12. What would factor into your company's cost-benefit analysis of this system?
    1. What are the possible economic benefits?
    2. What are the possible economic risks and liabilities?
13. In your opinion, would the additional cost of SideEyes® be economically justified?
14. Would federal or insurance incentives influence the decision on whether or not your company would adopt a SideEyes® system?
15. Would liability issues affect your decision?
16. What is the biggest issue or issues you see in using this technology?
17. In general, do you feel the SideEyes® system would be useful in your company?

Thank you for answering these questions. I have two more questions about your company.

Company Information

18. Approximately how many Class-A CDL drivers are employed by:
    1. Your terminal?
    2. Your company?
19. How many power units are in:
    1. Your terminal's fleet?
    2. Your company's fleet?

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REFERENCES

1. FMCSA (2012). Share the Road Safely. U.S. Department of Transportation. Retrieved on November 12, 2012 from http://www.sharetheroadsafely.org/nozone/nozone.asp.
2. Najm, W. G. and Smith, J. (2007). Development of Crash Imminent Test Scenarios for Integrated Vehicle-Based Safety Systems. DOT-HS-810-757. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.
3. Najm, W. G., Koopmann, J., Smith, J. D., and Brewer, J. (2010). Frequency of Target Crashes for IntelliDrive Safety Systems. DOT HS 811 381. Washington, DC: U.S., Department of Transportation, National Highway Traffic Safety Administration.
4. Jermakian, J. S. (2012). "Crash Avoidance Potential for Four Large Truck Technologies." Accident Analysis & Prevention, (49):338-346.
5. Federal Motor Carrier Safety Administration (FMCSA) (2010). Our mission. U.S. Department of Transportation Federal Motor Carrier Safety Administration. Retrieved on November 12, 2012 from: http://www.fmcsa.dot.gov/about/what-we-do/mission/mission.htm
6. Jula, H., Kosmatopoulos, E., and Ioannou, P. (2000, November). "Collision Avoidance Analysis for Lane Changing and Merging." IEEE Transactions on Vehicular Technology, 49(6), pp. 2295-2308.
7. Shinar, N. (1978). Psychology on the Road: The human Factor in Traffic Safety. New York: Wiley.
8. Najm, W.G. and Smith, J.
9. Najm, W.G., Koopman, J., Smith, J.D., and Brewer, J.
10. Jermakian, J.S., 338-346.
11. Garrott, W., Flick, M., and Mazzae, E. (1995). Hardware Evaluation of Heavy Truck Side and Rear Object Detection Systems. (SAE Technical Paper Series No. 951010). Society of Automotive Engineers: Warrendale, PA.
12. Bu, F., Chan, C.-Y. (2005). Pedestrian Detection in Transit Bus Application: Sensing Technologies and Safety Solutions. Proceedings of the IEEE Intelligent Vehicles Conference, Las Vegas, NV.

13 National Transportation Safety Board (2001). Special Investigation Report: Vehicle- and Infrastructure-based Technology for the Prevention of Rear-end Collisions. Retrieved from http://www.ntsb.gov/doclib/safetystudies/SIR0101.pdf on December 20, 2012.

14 Bu, F., Chan, C.-Y.

15. Gordon, C.C., Bradtmiller, B., Churchill, T., Clauser, C.E., McConville, J.T., Tebbetts, I., and Walker, R.A. (1989). 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics. Report No. NATICK/TR-89/044, U.S. Army Natick RD&E Center, Natick, Massachusetts. Retrieved on November 26, 2012 from: http://mreed.umtri.umich.edu/mreed/downloads/anthro/ansur/Gordon_1989.pdf

16 Jermakian, J.S., 338-346.

17. Mortimer, R.G., and Jorgeson, C.M. (1974). "Drivers' Vision and Performance with Convex Exterior Rearview Mirrors" (Paper No. 740961). Warrendale, PA: SAE.

18. Mourant, R. R. and DeNald, R.E. (1974). The Effects of Age and Visual Capability on Performance with Plane and Convex Mirrors. Proceedings of the Human Factors Society, 18, 123-128.

19. Wickens, C.D., & Hollands, J.G. (1999). Engineering Psychology and Human Performance (3rd Ed.). Upper Saddle River, New Jersey: Prentice Hall.

20. Sanders, M.S., and McCormick, E.J. (1993). Human Factors in Engineering and Design. (Seventh Ed.). New York, NY: McGraw-Hill, Inc.

21. Schaudt, W.A., Bowman, D., Trimble, T.E., Medina, A.F., Bocanegra, J., Baker, S., Marinik, A., Wierwille, W.W., and Hanowski, R.J. (in press). Enhanced rear signaling (ERS) for heavy trucks: Phase III–Development of Field Operational Test: Final Report. Contract No. DTMC75-07-D-00006, Task Order 2. Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration (Submitted September, 2010).

22. Sayer, J., Bogard, S., Funkhouse, D., LeBlanc, D., Bao, S., Blankespoor, A., Buonarosa, M. L., and Winkler, C. (2010). Integrated Vehicle-Based Safety Systems Heavy-Truck Field Operational Test Key Findings Report. Washington, D.C.: National Highway Traffic Safety Administration.

23 Wickens, C.D., & Hollands, J.G.

24 Sanders, M.S., and McCormick, E.J.

25. Hickman, J.S., Guo, F., Camden, M.C., Medina, A., Hanowksi, R.J., & Mabry, J.E. (2011). Onboard Safety Systems Effectiveness Evaluation: Final Report. Contract# DTMC75-09-C-00022. Washington DC: Federal Motor Carrier Safety Administration.

26. Fitch, G.M., Blanco, M., Camden, M., Olson, R., Stone, S., Mellichamp, D., McClafferty, J., Morgan, J.F., Wharton, A.E., Howard, H., Thomas, B., Alden, A., and Hanowski, R.J. (in press). Field Demonstration of an Advanced Heavy Vehicle Indirect Visibility System: Final Report. Contract No. DTNH22-05-D-01019, Task Order # 23. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

27 Sayer, J., et al.

28. SAE J2802: 2010: Blind-Spot Monitoring System (BSMS): Operating Characteristics and User Interface. Surface Vehicle Recommended Practice. SAE International. Warrendale, PA.

29. ISO 17387: 2008: Intelligent Transport Systems–Lane Change Decision Aid Systems (LCDAS)–Performance Requirements and Test Procedures. International Organizational for Standardization. Geneva, Switzerland.

30. Eberhard, C. D., Moffa, P. J., Young, S-K., and Allen, R-W. (1995). Development of Performance Specifications for Collision Avoidance Systems for Lane Change, Merging, and Backing. Task 4 Interim Report: Development of Preliminary Performance Specifications. DOT HS 808 430. TRW Space and Electronics Group. National Highway Traffic Safety Administration, Office of Collision Avoidance Research: Washington, D.C.

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