Federal Motor Carrier Safety Administration's Advanced System Testing Utilizing a Data Acquisition System on the Highways (FAST DASH)
Safety Technology Evaluation Project #2: Driver Monitoring
Final Report

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

November 2016

FOREWORD

The mission of the Federal Motor Carrier Safety Administration (FMCSA) is to reduce crashes, injuries, and fatalities involving large trucks and buses. A key focus of FMCSA is to provide leadership in the testing and evaluation of promising commercial motor vehicle (CMV) safety technologies so that these technologies can be implemented more rapidly and their potential benefits realized sooner. 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 program is to perform independent evaluations of promising safety technologies aimed at commercial vehicle operations.

For this study, an onboard monitoring system (OBMS) was evaluated. The OBMS was tested to assess the performance capabilities reported by the vendor and to verify connectivity of the OBMS to the Virginia Tech Transportation Institute's "NextGen" (next generation) data acquisition system. Finally, a field study implemented the OBMS within a revenue-producing fleet and the system was exercised on public roadways to gain an understanding of the system's potential safety benefits, system performance, unintended consequences, and impressions of the technology.

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16. Abstract
An independent evaluation of a non-video-based onboard monitoring system (OBMS) was conducted. The objective was to determine if the OBMS system performed reliably, improved driving safety and performance, and improved fuel efficiency in a commercial motor vehicle (CMV) operation. The study involved a controlled test on the Virginia Smart Road and a naturalistic field test with a CMV fleet. Controlled testing demonstrated capabilities for the field test. The field test demonstrated OBMS reliability with positive effects for safety but inconclusive effects for fuel efficiency. A reliability analysis indicated the OBMS provided speeding and seatbelt violations accurately 86 and 100 percent of the time, respectively. An analysis using the rate of safety-critical events (SCEs) per 10,000 miles found no reduction in SCEs from intervention to baseline. However, a trend analysis of violation frequency per 1,000 miles over vehicle operation weeks showed a significant drop in speeding violations (37 percent) and seatbelt violations (56 percent) from the baseline phase to the first 2-week intervention period. A subset of participating drivers in the field study were surveyed and indicated the OBMS was easy to use and felt it had a positive impact on their performance. Recommendations are presented for both system providers and fleets.

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Commercial motor vehicle, commercial safety technology, driver monitoring, independent evaluation

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SI* (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
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 (volumes greater than 1,000L 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 (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		Temperature (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/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

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 (2,000 lb)	T
		Temperature (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 and 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, ACRONYMS, AND SYMBOLS

Acronym	Definition
A^2B^4	2-month baseline and 4-month intervention
C	crash
CAN	controller area network
CDL	commercial driver's license
CMV	commercial motor vehicle
CRC	crash-relevant conflict
CVO	commercial vehicle operations
DAS	data acquisition system
df	degrees of freedom
dvX	frequency for hard brake
dvY	frequency for hard turn
dvZ	frequency for hard bump
EOBR	electronic on-board recorder
FAST DASH	FMCSA's Advanced System Testing utilizing a Data Acquisition System on the Highways
FMCSA	Federal Motor Carrier Safety Administration
GPS	global positioning system
ID	identification
km/h	kilometers per hour
MATLAB	technical computing software
MCMIS	Motor Carrier Management Information System
mi/h	miles per hour
NC	near-crash
NextGen	next generation, next "level up," a higher technology, new development
OBMS	onboard monitoring system

Acronym	Definition
OEM	original equipment manufacturer
SCE	safety-critical event
SCE-XCS	safety-critical event excluding curb strike
SD	standard deviation
SE	standard error
ULD	unintentional lane deviation
USB	universal serial bus
VMT	vehicle miles traveled
VTTI	Virginia Tech Transportation Institute

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EXECUTIVE SUMMARY

PURPOSE

A focus of the Federal Motor Carrier Safety Administration (FMCSA) is to provide leadership in the testing and evaluation of promising safety technologies developed for commercial motor vehicles (CMVs) such that their in-service benefits can be identified in a naturalistic driving environment. By identifying, quantifying, and documenting the safety benefits of promising technologies, FMCSA expects to positively influence the voluntary adoption of proven technologies by motor carriers. The goal of FMCSA's Advanced System Testing Utilizing a Data Acquisition System on the Highways (FAST DASH) program is to conduct efficient, independent evaluations of promising safety technologies aimed at commercial vehicle operations (CVOs). The current report details all tasks completed for FAST DASH Safety Technology Evaluation Project #2: Driver Monitoring.

For this study, an onboard monitoring system (OBMS) was evaluated. The tested OBMS—the waySmart® 820—is a fleet risk management system. Using vehicle kinematic and network data, accelerometers, and a global positioning system (but no video), the OBMS identifies unacceptable behavior and provides feedback to the driver, which is aiming at correcting the offending behavior within a given period of time. Examples of such behaviors include speeding (based on the posted speed limit or other pre-set criteria), driving aggressively (based on kinematic sensors), and lack of seatbelt use (also based on sensors). If the speed or seatbelt violation is corrected within the allowable period (e.g., speed reduced or seatbelt fastened), no violation (i.e., infraction identified by the system) is recorded. The system also monitors idling and approximates fuel usage by accessing data on the controller area network (CAN).

PROCESS

In this study, the Virginia Tech Transportation Institute (VTTI) conducted an independent evaluation of the waySmart 820 OBMS. The study process is described below:

- ***Controlled Performance Testing—***The research team performed preliminary "shakedown testing" of the technology in a controlled environment to exercise and assess the performance capabilities reported by the vendor (i.e., to determine the operational envelope). A secondary purpose of the shakedown testing was to verify the connectivity of the OBMS to the VTTI NextGen (next generation) data acquisition system (DAS).
- ***Field Study***—The OBMS has the potential to improve both safety and efficiency; however, its actual effectiveness depends on system reliability, validity, driver acceptance, "coaching" of drivers, and fleet manager interaction. The intent of the field study was to implement the OBMS within a revenue-producing fleet and exercise the system on public roadways to gain an understanding of the system's potential safety benefits, system performance under real-world conditions, unintended consequences, and driver and manager impressions of the technology.

RATIONALE AND BACKGROUND

FMCSA's *Large Truck Crash Causation Study* was the first-ever national study to attempt to determine the critical events and associated factors that contribute to serious large truck crashes.(1) Of the crashes analyzed in this study, 87.3 percent of the critical reasons attributed to the CMV (where the CMV was at fault) were assigned to driver error; 38 percent of those were specifically attributed to decision errors (e.g., speeding per conditions).(2) Separately, a 2013 survey of seatbelt usage in the United States among medium- and heavy-duty truck and bus drivers found that approximately 16 percent of CMV drivers were not wearing seatbelts at the time of observation.(3) According to the summary provided in *Large Truck and Bus Crash Facts, 2013*, of the 3,858 large truck drivers who died in crashes in 2013, 347 (9 percent) were not wearing any seatbelt.(4) Based on this previous research, speeding and seatbelt compliance are noteworthy areas to address.

Encouraging drivers to make safe choices when driving can save on equipment and operating costs, and—more importantly—save lives. Hickman and Geller demonstrated that teaching short-haul truck drivers to self-manage risky behaviors can be very effective at reducing activities such as extreme braking and speeding.(5) However, a later study by Hickman and Hanowski indicated that this strategy has challenges for application across revenue-producing fleets to maintain peer observation, feedback, and driver motivation.(6) In this later study, Hickman and Hanowski deployed an OBMS in a revenue-producing environment with professional CMV drivers. That study found that the number of safety-related events was significantly reduced from periods of driver performance without manager coaching or in-cab feedback to periods of driver performance with manager coaching and in-cab feedback. The OBMS technology in that study included video monitoring and accelerometers that triggered events for video capture.

The current study sought to evaluate a monitoring system that requires fleet management interaction. The tested monitoring technology varies significantly from other OBMSs, in that it applies kinematic measures (such as accelerometers) to track aggressive driving, but it does not capture video for manager review, which may make the driver less conscious of the monitoring system. The tested OBMS includes seatbelt usage monitoring and proprietary "Speed-by-Street™" monitoring, which compares real-time vehicle speed to pre-existing speed maps. A feature of the tested OBMS is its driver-vehicle interface display, which sounds an audible verbal alert when speeding, seatbelt, or aggressive driving criteria have been exceeded. Evaluation of the effectiveness and accuracy of this OBMS can serve to provide operating fleets with a better understanding of how to apply this technology, and technology vendors with a better understanding of how to improve their systems to meet the needs of fleets and their drivers.

CONCLUSIONS

Results from the controlled performance testing demonstrated the OBMS's capabilities for naturalistic collection and driving performance. The field study indicated that the OBMS performed reliably and had positive effects on driver performance and inconclusive effects on fuel efficiency.

- **OBMS reliably detects speeding and seatbelt violations.** Field testing demonstrated that the OBMS speed monitoring sensor correctly identified when CMV drivers were speeding (according to fleet-selected criteria) 86 percent of the time. The OBMS seatbelt monitoring sensor correctly identified when the driver's seatbelt was unfastened 100 percent of the time. Interestingly, the majority of seatbelt violations occurred in parking lots (85 percent) and at low speeds (less than 15 mi/h [24.1 km/h]; 93 percent).
- **Significant decrease in speeding.** The rate of speeding violations per 1,000 miles averaged across all drivers was significantly reduced (37 percent) from baseline to the first 2-week intervention period, when the OBMS started providing in-cab feedback.
- **Significant improvement in seatbelt use.** The rate of seatbelt violations was significantly reduced (56 percent) from baseline to the first 2-week intervention period and remained so throughout the entire intervention phase.
- **No significant change in safety-critical events (SCEs).** The field testing demonstrated neutral results regarding the effect of the OBMS on safe driving performance, as measured by SCEs. The mean rate of driver-at-fault SCEs (excluding curb strikes) per 10,000 miles during the intervention phase was not significantly lower than the mean rate during the baseline phase. However, the rate of driver-at-fault SCEs (excluding curb strikes) decreased for two-thirds of drivers.
- **No observed fuel usage improvement.** Collected drive file average fuel rates were compared between a group of drivers active in the intervention period and a group of drivers active in the baseline period (during a simultaneous 1-month period). The fuel efficiency results were inconclusive.
- **Positive driver and manager reviews.** A subset of drivers and fleet managers reported being able to understand and respond to the OBMS technology and found it beneficial and effective at improving safe driving performance.
- **Inconsistent/irregular fleet coaching.** Though the fleet management understood the involvement required for this evaluation, the research team observed that the fleet did not consistently follow the coaching protocol developed by the OBMS provider. For example, there was limited application of weekly email reports and limited use of the Web portal by fleet managers. It is likely that this lack of rigor may have had a negative impact on the realization of benefits of the tested OBMS. As an example, though a significant improvement in speeding violations was recorded in the early part of the study when driver violations were actively coached, the speeding rate returned to near baseline performance by the end of the intervention period, when it was observed that coaching had dropped off.

RECOMMENDATIONS

The evaluation of this specific OBMS provides some valuable guidance for both system providers and CMV fleets:

- **Suggestions for improving the OBMS technology.** Based on the results of this field test, opportunities for some improvement became apparent, including regular audits of metrics and configurations specific for truck speeds.
- **Suggestions for fleet coaching.** Active engagement between fleet managers and drivers should be regular and consistent to obtain the maximum benefit from the OBMS.
- **Industry application.** The tested OBMS may provide a useful resource for fleets desiring to improve safe driving performance (as clearly demonstrated in this study with seatbelt sensors). Fleets should consider their specific application needs when configuring OBMSs. Fleets should be conscious that occasional inconsistencies will exist in the systems and allowances should be made for drivers to provide manager feedback.
- **Better understanding of fleet manager-driver interaction.** Future evaluations of OBMSs should track fleet manager-driver interactions so that the exact frequency is known, and compare the effects of interactions between separate fleet entities or among drivers within a specific fleet.

FUTURE RESEARCH

This evaluation highlighted some areas for future research, such as the following:

- **Effective implementation of an OBMS.** Future research comparing effective and ineffective implementation methods is needed to provide a roadmap for fleets to follow when seeking to apply an OBMS to enhance driver performance and vehicle efficiency.
- **Setting effective fleet performance criteria.** A critical component that must be considered when implementing a kinematic OBMS is the vehicle dynamic thresholds. Most fleets are not equipped to run vehicle testing scenarios for calibration with full vehicle and load scenarios. While a fleet may feel confident setting a speed or seatbelt threshold based on policy, it most likely is not confident at setting thresholds for aggressive driving, which necessarily vary by the vehicle configuration (i.e., weight, single-unit, combination-unit) and transportation application (i.e., full load, less-than-load, dry, liquid, or hazardous materials). Joint cooperation among OBMS vendors, vehicle manufacturers, and vehicle testing centers is needed to develop a range of thresholds by vehicle configuration and application.
- **Development of an OBMS coaching program.** Long-term sustainable safety and efficiency improvements require consistent and sustained fleet coaching. Future research is needed to define effective coaching methods between fleet management and drivers, with the end goal being continuous improvement.

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.[(7)] The development, evaluation, and deployment of advanced safety technologies can assist in achieving this objective.

While there are numerous safety systems in development that have the potential to reduce crashes on our Nation's roadways, the benefits that these systems might provide may never be realized. While the reasons vary, one factor is the lack of supporting tests and evaluations to understand and communicate the underlying safety systems' true in-service benefits. FMCSA envisions, through cooperation with the trucking industry, promising commercial motor vehicle (CMV) safety technologies that support the expanding role of the trucking industry to transport the Nation's goods and products safely, securely, and efficiently. Implementation of vehicle safety technologies—such as passive and active collision mitigation and active driver behavior monitoring—could reduce large-truck and bus crashes. Data to assess 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 these technologies can be implemented more rapidly and their potential benefits realized in the commercial trucking industry. 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 goal of FMCSA's Advanced System Testing Utilizing a Data Acquisition System on the Highways (FAST DASH) program is to perform efficient independent evaluations of promising safety technologies aimed at commercial vehicle operations (CVO). The vision of this technology transfer program is to provide technology insight to the commercial trucking industry in hopes of promoting the adoption 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 and safety manager subjective opinions).

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

The FAST DASH technology evaluation process commenced with a solicitation for technology candidates to submit their interest in partnering with VTTI to assess their systems. The research team developed and posted a sources-sought notice via a dedicated FAST DASH Web page for the purpose of soliciting proposals from safety technology vendors (see Appendix A). A technology vendor statement of work (SOW) providing details on the FAST DASH program and the requirements for proposal submission was made available on this Web page. In addition to posting the sources-sought notice, researchers created a list of potential technology vendors and notified them of the Web page 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. Eight technology vendors submitted proposals for a total of nine safety systems/technologies. VTTI researchers conducted an initial review of these proposals and categorized the safety technologies by type, potential safety benefits, and ease of implementation. A decision matrix was used to identify, analyze, and rate the technology applicants systematically. Each technology applicant was given a rating on a scale of 1–10 for meeting 14 relevant criteria, such as FMCSA's area of authority, FMCSA's mission, expected safety effectiveness, technology maturity, fitness for research, and prior research. These criteria were assigned weights by the FAST DASH team (i.e., FMCSA and VTTI). A total score was computed for each technology applicant. These scores were used in selection discussions and helped differentiate the technologies, but were not the sole determinant for choosing a technology.

All technology proposals were presented to the contracting officer's representative (COR) and other FMCSA personnel for consideration. After a thorough review, a final candidate was selected by FMCSA. A driver monitoring system—the waySmart® 820 (see Figure 1), developed by inthinc™ Technology Solutions, Inc. (inthinc)—was selected for evaluation (see Appendix B). This technology monitors the driver's driving habits, such as speeding, aggressive maneuvers (i.e., hard accelerations and braking, severe turning and swerving, and hard bumps), and seatbelt usage through various sensors and data from the vehicle's J1939 or J1708 controller area network (CAN) bus. When the system detects that the driver is speeding, driving aggressively, or not wearing a seatbelt, it issues an in-cab, real-time verbal and audible feedback alert to the driver. If the driver fails to correct the behavior, a violation is transmitted back to the company's designated reviewer (e.g., safety manager/driver manager). More information about the tested onboard monitoring system (OBMS) technology can be found in Section 3.2.2.3.

Figure 1. Photograph. The tested OBMS driver interface and controller unit hardware.

1.2 PROBLEM SCOPE

FMCSA's Large Truck Crash Causation Study was the first-ever national study to attempt to determine the critical events and associated factors that contribute to serious large truck crashes.[(8)] Of the crashes analyzed in this study, 87.3 percent of the critical reasons attributed to the CMV (where the CMV was at fault) were assigned to driver error; 38 percent of those were specifically attributed to decision errors (e.g., speeding per conditions), 28.4 percent to recognition errors (e.g., not paying attention), 11.6 percent to non-performance errors (e.g., falling asleep), and 9.2 percent to performance errors (e.g., poor directional control).[(9)] Separately, a 2013 survey of seatbelt usage in the United States among medium- and heavy-duty truck and bus drivers found that approximately 16 percent of CMV drivers were not wearing seatbelts at the time of observation.[(10)] According to the summary provided in *Large Truck and Bus Crash Facts, 2013*, of the 3,858 large truck drivers who died in crashes in 2013, 347 (9 percent) were not wearing any seatbelt, 10 (0.3 percent) were wearing a shoulder belt only, and 52 (1.3 percent) were wearing a lap belt only.[(11)] An additional 269 fatalities (7.0 percent) did not have a record of the seatbelt usage (i.e., it was not reported).

A recent summary of truck and bus driver violations collected from FMCSA's Motor Carrier Management Information System (MCMIS) demonstrated that failing to use a seatbelt while operating a CMV was among the top five violation categories in 2013.[(12)] A 2013 survey of seatbelt usage in the United States among medium- and heavy-duty truck and bus drivers found an overall usage rate of 84 percent, up from 78 percent in 2010.[(13)] Rates were highest in the western region (91 percent), including Hawaii and Alaska, and lowest in the northeastern region (76 percent). Central and southeastern regions, including Texas, had rates of 79 percent and 83 percent, respectively. Usage rates were greater on expressways (86 percent) than on surface streets (78 percent), and greater when driving in heavy traffic (85 percent) versus light traffic (71 percent). These data suggest that across the United States, 16 percent of truck drivers are not consistently wearing seatbelts (on average).

Based on this previous research, speeding and seatbelt compliance are noteworthy areas to address. Encouraging truck drivers to make safe driving choices (e.g., avoiding speeding and aggressive driving and wearing their seatbelts) would benefit both the drivers' personal safety and the safety of surrounding vehicle operators. The current study sought to evaluate a monitoring system that requires fleet management interaction. The tested monitoring technology varies significantly from other OBMSs, in that it applies kinematic measures (such as accelerometers) to track aggressive driving, but it does not capture video for manager review, which may make the driver less conscious of the monitoring system.

The tested OBMS includes seatbelt usage monitoring and proprietary "Speed-by-Street™" monitoring, which compares real-time vehicle speed to pre-existing speed maps. A significant feature of the tested OBMS is its driver-vehicle interface display, which sounds an audible verbal alert (e.g., "check your speed") when speeding, seatbelt, or aggressive driving criteria have been exceeded. For the speed and seatbelt alerts, the OBMS allows drivers a brief grace period to correct performance in either of those categories before recording a violation visible to fleet managers. It is worth noting that the participating fleet's application of the OBMS included delivery of weekly report cards to fleet managers, but not to drivers. The OBMS interactions included real-time, in-cab verbal alerts for drivers and weekly emailed summaries and Web portal access for fleet managers. Fleet managers were instructed and encouraged by the OBMS technology vendor to provide regular driver coaching based on weekly emailed reports. The OBMS also provided feedback to managers regarding idling time and approximate fuel usage.

This study investigated the effectiveness of the OBMS in affecting active safety performance (speeding and aggressive driving), passive safety performance (seatbelt usage), and vehicle fuel usage. This study also measured the system's accuracy in recognizing when the criteria were exceeded by the driver for speeding, aggressive driving, and seatbelt parameters.

1.3 ORGANIZATION OF THE CURRENT REPORT

The current report details all tasks completed during the second FAST DASH safety 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

An OBMS was installed in a test tractor-truck without trailer at VTTI. The OBMS was also connected to the data acquisition system (DAS). The test tractor-truck was driven on the Virginia Smart Road and surrounding public roads while the OBMS and DAS were actively collecting driver performance and vehicle data. This section discusses the twofold purpose of the dynamic testing and the results of the testing that were applied to the field study.

1.3.2 Field Study

A fleet was selected for participation in the current field study early during the first FAST DASH safety technology evaluation project. Primary factors that were considered during the selection process included the number of trucks and drivers available at the participating fleet, the proximity of the fleet's terminal to both team headquarters, and the fleet management's willingness to provide research and vendor team access to the trucks. Twenty CMVs were instrumented with the research team's DAS and the OBMS. Data were collected for approximately 11 months, resulting in 1,450,459 miles (2,334,289 km) of data. Evaluation methods and study results are discussed in this section.

1.3.3 Conclusions

Conclusions found across all methods of technology evaluation are discussed in this section. These methods include preliminary performance testing, safety performance (e.g., safety-critical event [SCE] comparison and driver violation trends), OBMS performance, effects on fuel usage, and qualitative data from a subset of drivers and fleet managers.

1.3.4 Recommendations

Based on the findings of this evaluation, the research team has provided suggested improvements to the technology in this final section. These improvements could be applied to all OBMSs (not just the tested technology).

2. CONTROLLED PERFORMANCE TESTING

2.1 DYNAMIC TESTING (VIRGINIA SMART ROAD)

Preliminary performance testing was performed in a dynamic setting on the Virginia Smart Road and on local roads and highways. All dynamic testing was performed with researchers and engineers (i.e., no naive participants). Multiple testing runs were performed with two primary purposes: to evaluate how the OBMS features operate on a test tractor-truck, and to determine how the OBMS interfaces with the VTTI DAS.

The purpose of the dynamic testing was not to determine what the absolute right parameters should be to make the OBMS effective in a commercial trucking operation. Rather, it was to prepare for data collection during the field test, using the OBMS provided by the technology vendor and per the agreement with the fleet.

2.1.1 Setup

An OBMS device was delivered to VTTI by the technology provider for testing on a tractor-truck. The OBMS was installed in a 1995 Peterbilt 379 in conjunction with the VTTI NextGen DAS. The connection between the OBMS and the DAS was made through a serial-to-universal serial bus (USB) cable. The technology provider configured the OBMS according to the test tractor-truck prior to shipping. A laptop was connected to the DAS through an internet protocol cable. Therefore, the system connections were linked along the following series: vehicle to OBMS, OBMS to DAS, and DAS to test laptop. This connection allowed the researchers to observe the vehicle–OBMS parameters through a proprietary software interface on a test laptop. These parameters are described in Section 3.2.2.3 ("OBMS Description") and included speeding start time and limit, speeding stop time and limit, and violation event record and time. Therefore, the software interface gave the researchers a real-time look at the parameters that were intended to be collected by the DAS as measured by the OBMS.

2.1.2 Shakedown Testing Trials

For the testing trials, a trailer was not connected to the tractor. After installation of the OBMS, the research team administered at least three dynamic vehicle trials (on the Virginia Smart Road and local routes) based on OBMS features that were being evaluated. Trials on public roads were performed using roads with limited traffic or on highways where exceeding the posted speed limit by 5 mi/h (8.0 km/h) would not create an operational risk.

2.1.3 Onboard Monitoring System Feature Evaluation

The research team confirmed the availability of three OBMS violation categories:

- A record of audible alerts.
- The OBMS record of vehicle performance when performance criteria were exceeded.
- A record of alerts that exceeded the grace period and resulted in violations.

During the test trials, the process of verifying the audible alerts was straightforward. The study team confirmed recordings of audible alerts, OBMS measures of vehicle performance, and violations by observing the live status of the parameters on the test laptop that was connected to the DAS. The research team also investigated the DAS recordings after the trials using proprietary post-processing software. This post-processing software, created by VTTI software developers, allows the researchers to view video data aligned with time-series data graphs. Options allow researchers to navigate to a specific event, view video, view data graphs, view maps and satellite images, play video at various speeds, and step through the video one frame at a time. The platform also provides an interface for entering and saving responses to the variables in the data dictionary, which can be in the form of questions (e.g., drop-down boxes, check boxes, text boxes) or time-series video coding.

The application of the three violation categories (i.e., seatbelt, speeding, and aggressive driving) required use of the Virginia Smart Road in addition to public roads. The seatbelt violations could be evaluated on any road because the criteria were straightforward to apply. The seatbelt magnetic reed switch had to be an open circuit (i.e., seatbelt buckle unlatched) and the absolute vehicle speed had to be greater than or equal to 5 mi/h (8.0 km/h). For the OBMS to monitor speeding, the tractor-truck had to be driven on public roads with posted speed limits (which are not present on the Virginia Smart Road). The aggressive driving violations were tested primarily on the Virginia Smart Road due to the nature of the abrupt vehicle maneuvers applied during those trials. These maneuvers included hard turns, hard accelerations, and hard braking. The research team attempted to set off hard-bump violations by performing maneuvers on a local street with speed bumps in Blacksburg, VA.

2.1.3.1 Results

The research team confirmed the audible alerts, vehicle performance violations, and seatbelt violations during and after the in-vehicle test trials. The seatbelt violation consistently activated whenever the switch was disconnected (buckle unlatched) and the tractor-truck was moving faster than 5 mi/h (8.0 km/h). The research team also confirmed the audible alerts, vehicle performance violations, and violations for speeding. It was apparent during the test trials and upon later review of collected data that some public roads challenged the OBMS's ability to accurately predict the posted speed. At least one two-lane road speed zone was predicted to be 5 mi/h (8.0 km/h) higher than the actual posted speed limit. Furthermore, one four-lane highway speed zone changed from a posted limit of 65 mi/h (104.6 km/h) to a posted limit of 55 mi/h (88.5 km/h) near a main crossroad, and the OBMS failed to recognize the speed zone reduction.

Due to the nature of the aggressive driving violations, confirmation was limited to the types of violations that could be produced during the test trials. The research team successfully activated and recorded hard-turn and hard-brake aggressive violations. The resultant g-forces related to the hard-turn and hard-brake violations were measured after the recorded vehicle performance data were ingested into the VTTI database and reviewed in analysis software. The research team determined that these violations activated when vehicle accelerations met or exceeded 0.5g; however, the hard acceleration violation could not be produced during the evaluation. The research team was also unable to activate the hard-bump violation, despite aggressive approaches over speed bumps. The hard acceleration and hard-bump violations were not tested further due to safety concerns and concerns related to damaging equipment.

The results of the evaluation trials were shared with the technology provider, who determined that the configuration of the aggressive driving criteria had been left at default settings (which are commonly applied to light vehicles) prior to delivery of the OBMS test device to the research team. This meant that the criteria for activating the aggressive driving violations may have been too conservative during the shakedown evaluation. In other words, a heavy CMV tractor without trailer that weighs approximately five times more than a light vehicle would need to be able to brake, accelerate, turn, and bump at the same rate as a light vehicle to set off the aggressive driving sensors. These findings reinforced the need for a calibration drive event with the fleet during the early stages of the naturalistic data collection to confirm that the OBMS settings would match the characteristics of the field operational vehicles and the fleet's policies, accordingly.

2.1.4 Onboard Monitoring System-to-Data Acquisition System Interface Evaluation

The other purpose of the shakedown testing was to verify that the OBMS would interface with the DAS through the serial-to-USB cable, allowing the DAS to record the OBMS performance parameters during real-time trips in each field test vehicle.

The following variables were created by the OBMS and collected by the DAS:

- **Speeding Start:** Sent when the vehicle speed exceeded the speed limit plus the allowed speed buffer (5 mi/h [8.0 km/h]).
- **Speeding Stop:** Sent when the vehicle speed was less than the speed limit plus the allowed speed buffer (5 mi/h [8.0 km/h]).
- **Seatbelt Start:** Sent when the seatbelt was unbuckled and the vehicle exceeded the configurable seatbelt speed limit (5 mi/h [8.0 km/h], absolute vehicle speed).
- **Seatbelt Stop:** Sent when a seatbelt violation was in effect and the seatbelt was either buckled or the vehicle dropped below the configurable seatbelt speed limit (5 mi/h [8.0 km/h], absolute vehicle speed).
- **Hard Turn:** Sent when a hard turn occurred in the vehicle. The variable was coded as "AggressiveDriving_dvy" (positive and negative values).
- **Hard Brake:** Sent when a hard brake occurred in the vehicle. The variable was coded as "AggressiveDriving_dvx" (positive values).
- **Hard Acceleration:** Sent when a hard acceleration occurred in the vehicle. The variable was coded as "AggressiveDriving_dvx" (negative values).
- **Hard Bump:** Sent when a hard bump occurred in the vehicle. The variable was coded as "HardBump_PeaktoPeak" (positive and negative values).
- **Violation (Alert) Audio:** Sent when the seatbelt or speeding alert audio was played by the OBMS. The frequency of these audio alerts occurred at the time the criteria were exceeded and repeated every 10 seconds until the performance criteria returned to allowable levels.

- **Violation Timeout Exceeded:** The speeding and seatbelt violations had a grace period of 15 seconds from the time that the criteria were exceeded. This violation was sent once that grace period expired.

2.1.4.1 Results

As described above, the DAS successfully collected seatbelt, speed, and aggressive driving violations that were activated during the testing trials. Section 3.3.3 discusses violation activation, violation records, and related audible alerts in more detail.

3. FIELD STUDY

The research team investigated the effectiveness of the OBMS 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 oftentimes 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 can provide insight as to why an incident may have occurred and what might have been done to prevent it from happening. The research team selected a naturalistic data collection approach for the current field study because of its ability to:

- Evaluate the safety benefits and potential unintended consequences of using the OBMS.
- Explore driver acceptance.
- Observe overall system performance and reliability.

The study team applied three measures to investigate the safety benefits of the OBMS. These measures were based on a before-after study design to compare driver performance during the baseline phase (i.e., before the OBMS driver in-cab and manager feedback were enabled) with driver performance during the intervention phase (i.e., after the driver in-cab and manager feedback were enabled). The first safety benefit measure was the rate of SCEs per 10,000 miles (16,093 km) of driving. For the purposes of this study, SCEs consist of all valid events that can be classified into five basic event types: crashes, tire strikes, near-crashes, crash-relevant conflicts, and unintentional lane deviations (see Table 1). The second and third safety benefit measures were the frequency and persistence of change in the number of speeding and seatbelt violations that were recorded for each driver per 1,000 miles (1,609 km) between the baseline and intervention phases.

Table 1. 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 Lane Deviation	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 research team also evaluated the performance of the OBMS using data collected during the field test. Finally, the research team surveyed a sample of participating drivers and safety managers to determine user opinions on the tested OBMS.

3.1 STUDY DESIGN

The research team evaluated the potential safety benefits of the OBMS using a naturalistic driving before-after study to compare driver performance during the baseline period (i.e., before the system was enabled) with driver performance during the intervention phase (i.e., after the system began providing in-cab feedback to the driver). Following the study design of the first FAST DASH safety technology evaluation project, an A^2B^4 model was selected for the current study where "A" and "B" refer to the baseline and intervention phases, respectively.[14] The superscript refers to the number of months in each phase (e.g., "2" refers to 2 months). A power analysis conducted in the first FAST DASH safety technology evaluation project indicated that 20 CMVs at a correlation value of more than 0.8 (see Table 2) would provide a conservative estimate for sufficient power for statistical significance testing at the conclusion of this current data collection.

Table 2. Power analysis results for an A^2B^4 design using data from generated data set representative of a daytime heavy-vehicle data collection effort.[15]

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

3.2 METHOD

3.2.1 Fleet and Drivers

As with the first FAST DASH safety technology evaluation project, the research team evaluated multiple fleets for participation in the FAST DASH program (i.e., fleets that have participated in previous studies with the research team in addition to new fleets).[16] The research team evaluated the final list of potential fleets and selected one that would meet the needs of both the research team and the OBMS technology provider. Three 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 ability and willingness of the fleet's management to facilitate research and vendor team access to the trucks for installation and maintenance of the OBMS and the DAS equipment by the research and technology vendor teams.

Based on these criteria, the research team approached the same fleet that participated in the first FAST DASH safety technology evaluation project.[17] This fleet is a mid-sized fleet operating out of a terminal located in Kernersville, NC, managing 85 power units (tractors) and approximately 98 drivers. Of these 85 power units, 38 were assigned to a dedicated contract with the fleet's client; the remaining 47 were assigned to a for-hire fleet. A broad assortment of routes was assigned to the dedicated power units that consisted mostly of long-haul deliveries in the United States and Canada, while the for-hire fleet was assigned to day trip and multi-day trip regional routes. Those two groups of dedicated/for-hire trucks and associated drivers were considered an excellent pool for the potential recruitment of approximately 20 drivers.

3.2.2 Apparatus

3.2.2.1 Trucks

Twenty-five Class 8 tractors (24 sleeper-berth and 1 day-cab) were instrumented for this study. Ten were manufactured in 2012, 3 in 2013, and 12 in 2014. Each tractor exclusively hauled 53-foot (16-meter) box-van trailers during the study. Driver and truck attrition during the participant consent and baseline data collection phases created challenges and forced the research team to extend the recruitment and data collection periods. The consent process for drivers and vehicle instrumentation continued until at least 20 drivers and tractors were simultaneously involved in the study and contributing data. This explains why more than 20 driver consents and vehicle installations were required.

Due to the nature of the study, it is worth noting a few additional features that were present on the power units during the study. An electronic logging system was pre-installed at the fleet's choice as part of the fleet's normal operating policy. Additionally, the power units were equipped with electronic-stability and roll-stability control systems. The power units were equipped with standard cruise control, which did not include adaptive cruise technology. The fleet also had a vehicle governor set on each power unit at 65 mi/h (104.6 km/h) when not on cruise and 68 mi/h (109.4 km/h) when on cruise.

3.2.2.2 Data Acquisition System

The research team instrumented each participating CMV with a VTTI NextGen DAS (see Figure 2). The DAS captures three general groups of measures:

- DAS sensor measures (described below).
- Vehicle network measures.
- Add-on measures from the OBMS units (i.e., audio alert data and driver performance data related to speeding, seatbelt use, and aggressive driving).

During the evaluation period, the DAS collected these data to assist in determining the operational performance of the OBMS as measured by metrics such as the frequency and severity of SCEs. The DAS collected data from vehicle "ignition on" to 5 seconds after "ignition off," and it saved the data continuously throughout the data collection period. For any vehicle without an auxiliary power unit, the DAS shut off after 5 minutes of no change in global positioning system (GPS) location. Research team personnel periodically retrieved the DAS data. The general design characteristics of the VTTI NextGen DAS are as follows:

- 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.
- Does not require permanent modifications to the vehicle.
- Minimal space requirement (e.g., for data storage unit).
- Automatic start-up, shut-down, 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 (15 hertz) to capture the driver's face and rearward and forward scenes.
- Rugged and built for crash survivability.

Figure 2. Photograph. The NextGen DAS positioned behind the passenger seat.

Research team personnel unobtrusively installed a DAS unit in each participating vehicle to facilitate naturalistic driving behavior monitoring with the OBMS during on-road settings. The DAS equipment was placed behind the passenger seat, concealed from the driver (see Figure 2). Cameras mounted inside the cab were in a small protected housing located on the center of the windshield (see Figure 3). All wires and other data-recording equipment were professionally routed under interior panels.

Figure 3. Photograph. DAS forward and face camera mounted on windshield.

The NextGen DAS uses a 24-gigahertz universal medium-range radar (installed on the front bumper, in center position) for object tracking and ranging measurement. In addition, the DAS records multi-channel H.264 compressed video/audio on a custom electronics package designed specifically for automotive use. Color and black-and-white video cameras record three external views and one internal view. The three external views include 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—see Figure 4), and one down the passenger-side adjacent lane (camera positioned on the passenger-side front fender, facing rearward). The internal view includes a front view of the driver's head and shoulders (camera positioned on the windshield just left of center—see Figure 5). Other non-video data collected include turn signal use, other vehicle position/distance, speed, lateral/longitudinal g-forces, yaw rate, and continuous audio. The DAS interfaces with the vehicle's J1939 CAN bus via the original equipment manufacturer (OEM) onboard diagnostic port to collect data such as speed and mileage. In this study, the J1939 CAN bus was taped directly behind the dash.

Figure 4. Photograph. DAS driver-side, rear-facing side camera mounted on fender.

Figure 5. Photograph. Four camera images multiplexed into a single image.

The NextGen DAS sensors include:

- **GPS:** A GPS device used primarily for tracking the instrumented vehicles and placing them in time and space. Data output includes measures of latitude, longitude, altitude, horizontal and vertical velocity, heading, and status and strength of satellite acquisition.
- **Lane Tracker:** An in-house-developed lane tracker, called the "Road Scout," is included in the DAS. The Road Scout is a custom machine-vision process that runs concurrently on the DAS and grabs video frames from the forward camera feed. Note that the

"grabbed" video frames are not stored, but instead, are 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 Onboard Monitoring System Description

The technology vendor (inthinc) developed the OBMS technology and was responsible for installing it on participating vehicles (see Figure 1). The OBMS included a touchscreen display that was mounted near the center of the dash to provide easy access for the driver. The antenna associated with this system was mounted on the exterior back wall of the cab, and the system's central processing unit was mounted to the cab floor, under the sleeper-cab lower bunk (accessible through the passenger-side luggage door). There was also one day-cab in the study; in this case, the main box was placed under the passenger seat, alongside the DAS unit.

The touchscreen display also contained a speaker. The speaker was used to provide feedback to the driver via audible, in-cab verbal alerts, including the following: "check your speed," "please fasten your seatbelt," and "aggressive driving." This audible feedback is referred to as "audible alerts" for the remainder of the report. The audible alerts were only active during the intervention phase of the study. During the baseline phase, the audible alerts were silent, meaning that the drivers were not informed of any performance infractions. Likewise, the OBMS did not communicate directly with fleet managers during the baseline phase, either through emailed reports or Web portal access. However, during the intervention phase, the audible alerts were provided to drivers when the acceptable vehicle performance criteria were exceeded. The vehicle performance criteria were set by a combination of recommended default settings from the OBMS developer and with approval from the partnering fleet. Parameters/criteria for acceptable vehicle performance were as follows:

- **Speeding:**
  - Vehicle speed less than 5 mi/h (8.0 km/h) above the posted speed limit.

- Posted speed limit was identified by inthinc's proprietary Speed-by-Street™ technology.

- **Seatbelt:**
  - Vehicle speed less than 5 mi/h (8.0 km/h).
  - Seatbelt is buckled.
- **Aggressive Driving:**
  - Hard brake: +2.
  - Hard turn: +3.
  - Hard bump: 0.
  - Hard acceleration: +6.
- **Audio Setting (not adjustable):**
  - 85 decibels (dB) at 1 meter.

When OBMS instrumentation of the fleet power units began, the OBMS was configured to the vehicle performance criteria previously described. The calibration was completed at a dynamic driving event at the fleet's service warehouse. Attendees included an engineering configuration expert from the OBMS parent company and representatives from the fleet's safety and service management teams. During the calibration, a fleet service technician drove the truck and the representatives from fleet management and the OBMS vendor rode along as passengers. The calibration drive route was performed with only a power unit (no trailer attached) in an abandoned parking lot near the fleet center. This setup was due to the nature of the aggressive vehicle dynamics that needed to be experienced and selected by the calibration team to ensure that vehicle performance criteria would meet the fleet's safe operating policies. The selected performance criteria were then applied to all OBMSs throughout the duration of the baseline and intervention phases.

The in-cab audible alerts for speeding and seatbelt violations were provided every 10 seconds after the infraction, starting just after the OBMS observed the infraction. The audible alerts continued at 10-second intervals, with some delays built in to avoid annoying the drivers, until the performance criteria related to the alert were satisfied. The speeding and seatbelt alerts had a grace period associated with them. The OBMS would not record a speeding or seatbelt violation or report it to the Web portal unless the performance criteria were exceeded for 15 seconds after the first audible alert was provided to the driver. Given the 10-second intervals for audible alerts, drivers were given at least two warnings that vehicle performance criteria for speeding or seatbelt usage had been exceeded before the infractions were recorded. However, when the vehicle exceeded the aggressive driving criteria, an immediate record of that infraction was made along with at least one audible alert provided to the driver. Violation records would not be repeated for a given vehicle activity (e.g., speeding) unless the criteria were satisfied and then exceeded again. Therefore, each decision by drivers to exceed the criteria was not double-counted.

The tested OBMS had some available features that were not applied during the study, per the fleet's choice. An electronic logging system is available as standard equipment with the OBMS.

Because the fleet already had an electronic logging system installed in its power units, the fleet chose not to apply the OBMS option. During the intervention phase of the study, participating drivers were asked to confirm their status with the vehicle by logging in approximately once a day; this was to help confirm each participating driver's identification and association with the assigned power unit.

The DAS units were connected to the OBMS through a serial-out to USB-in connection. The DAS units were set up to record parameters from the OBMS. Not all of the parameters provided to the DAS were provided to the Web portal. For example, the DAS made a frequent record of instances when an audible alert was triggered in each OBMS vehicle unit; however, that information was not reported to the Web portal (or elsewhere) as a violation. The following parameters were recorded on the DAS from the OBMS:

- **Speeding:**
  - Criteria fail time and status.
  - Speeding start time and limit.
  - Speeding stop time and limit.
  - Audible alert time.
  - Violation record time.
- **Seatbelt unbuckled:**
  - Criteria fail time and status.
  - Seatbelt start time.
  - Seatbelt stop time.
  - Audible alert time.
  - Violation record time.
- **Aggressive driving:**
  - Lateral linear acceleration criteria fail time and g-force.
  - Longitudinal linear acceleration criteria fail time and g-force.
  - Vertical linear acceleration criteria fail time and g-force.
  - Audible alert captured only in WAV files.
  - Violation record time—immediately applied at criteria fail.

The speeding alerts and violations were provided to the driver of each power unit in real-time. The OBMS determined the state of the vehicle speed based on a connection to the vehicle CAN bus. The OBMS determined the location of the vehicle and roadway using GPS technology. It determined the status of the roadway speed based on a proprietary system called Speed-by-Street™. This standard feature of the OBMS is based on three sources of information:

- Data provided through a partnership with a leading global provider of digital map data.

- A series of editing and auditing exercises performed by the company on frequently traveled customer roads.
- User feedback on its online portal.

The data provided by the mapping partner contain speed limit data for metropolitan streets and highways and interstates. These data also classify roads based on speed categories, ranging from 1 (i.e., greater than 80 mi/h [128.7 km/h]) through 8 (i.e., less than 6 mi/h [9.7 km/h]). If a vehicle and device travel down a road without precise knowledge of the speed limit, the upper limit of the road category is provided to the driver as the speed limit. The feedback from the online portal allows fleet managers to report feedback from their drivers by selecting specific violations that have been highlighted on the vehicle list. The vehicle list includes GPS coordinates or road names and thus identifies the specific roadway and/or zone where the system-reported speed does not match the posted limit.

The OBMS fleet manager portal provides summaries and detailed reports on driver and vehicle performance. The portal can be configured to view team summaries or detailed information on individuals. The summaries of past performance can be selected to cover the previous week, month, or year. Current tracking of vehicle units can be identified in real-time and shows location and status. Driver and team scores are calculated by an algorithm that increases the score penalties for higher severity events, such as speeding greater than 15 mi/h (24.1 km/h) above the posted speed limit or seatbelt not fastened at highway speeds. A generic example of a driver report list is provided in Figure 6. The overall score and scores for driver style (including speed and aggressive driving performance) and seatbelt are available. Details on individual performance are also available in the form of charts, figures, and lists (see Figure 7). For example, a fleet manager can determine the exact location of a speeding violation in a map view that highlights the road’s speed limit, vehicle maximum speed, and distance driven during the violation. The portal can also be used to change preferences for email or other notifications. These notifications can provide managers with weekly report cards or flag events of interest that happen in real-time.

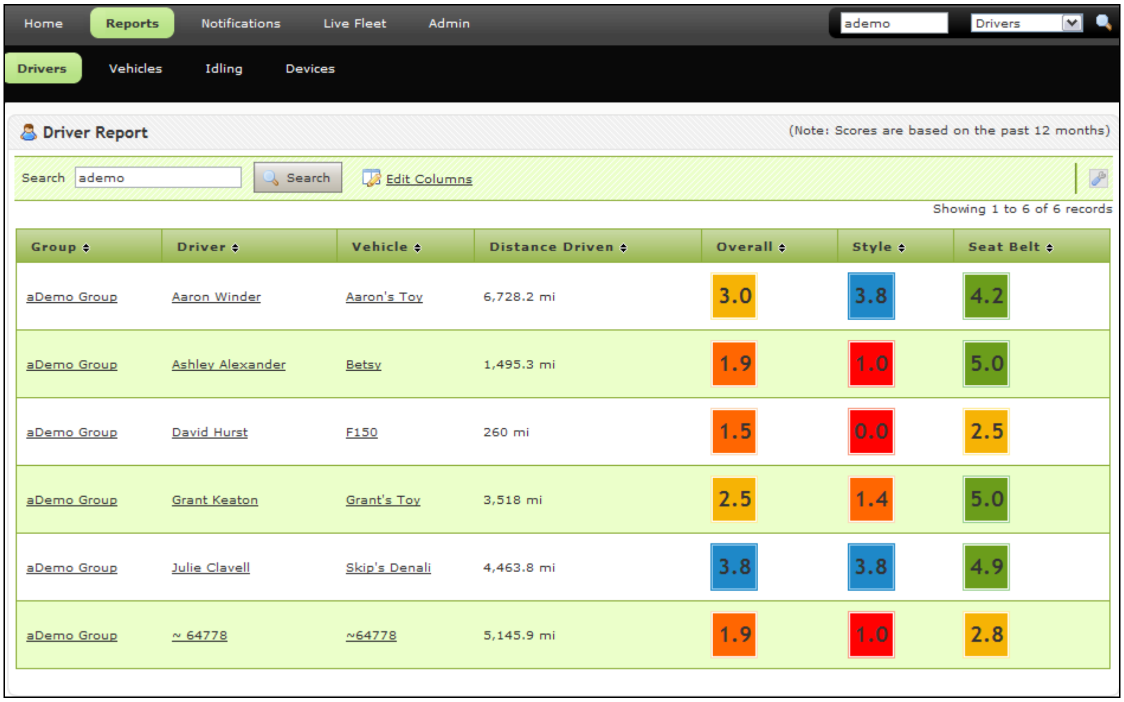

Figure 6. Marketing screenshot. Driver-monitoring system Web portal, driver report view.

Note: Names and values shown do not represent actual driver identities or performances.

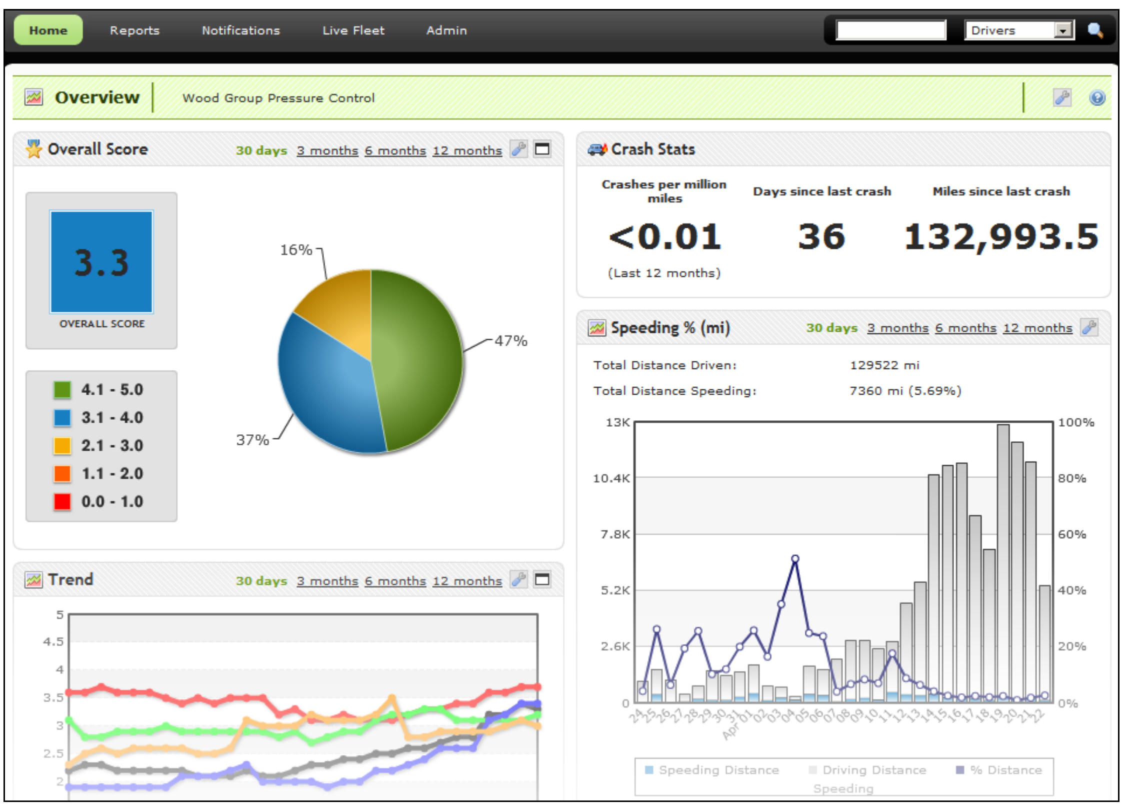

Figure 7. Marketing screenshot. Driver-monitoring system Web portal, driver performance detail charts.

Note: Data shown do not represent actual driver performance.

3.2.3 Driver Recruitment Process

The research team worked with the fleet to recruit drivers for participation, making frequent recruitment visits to the terminal's location. The methods of communication used for driver recruitment are as follows:

- Recruitment flyers/information posted in common areas.
- In-person communication utilizing an announcement script prepared by the research team.
- Phone contact (based on the previous FAST DASH study with the same fleet).

Participants were eligible for inclusion in the study if they met all of the following criteria:

- Must be at least 21 years of age.
- Must hold a valid Class A commercial driver's license (CDL) with expiration date outside of the study date range.
- Must have at least 2 years of experience driving commercial vehicles.
- Must have a visual acuity of 20/40 or better.
- Must be able to operate a tractor-trailer.
- Must be willing to have driving time recorded (video and audio) for 6 months.

All study protocols were approved by the VTTI Human Assurances Committee Institutional Review Board. Participating drivers read and signed an informed consent form and received compensation for their participation.

When drivers indicated interest in study participation, they were escorted to a private area of the terminal by a member of the research team and provided with an informed consent form to review. Before each driver signed the consent form, the researcher answered any questions. The researcher explained that the OBMS would be deactivated for at least the first 2 months of participation; however, the research team's DAS would be actively recording video, audio, and kinematic data during that time, and the participant should drive as he or she normally would. Participants were also instructed that after the OBMS was activated, a fleet safety manager or member of the research team would provide a review of system functionality and any training necessary to operate the system.

After both parties (i.e., driver and researcher) signed the informed consent form, each driver was required to show a valid Class A CDL. Then, a brief screening interview was completed, which included a visual acuity test and other forms and questionnaires for some drivers (see Appendices D and E).

The research team also recruited two fleet managers to participate in a post-study interview. The managers reviewed and signed an informed consent form. See Appendix E for a list of questions asked by the research team during this interview. Fleet managers were not compensated for their participation.

3.2.4 Data Reduction

3.2.4.1 Participant Verification

The research team reviewed each file recorded by the DAS to verify that the participant was indeed operating the vehicle. Any recorded drivers who were not consented study participants were excluded from further reduction.

3.2.4.2 Data Quality Control and Safety-critical Event Reduction

Once they were transferred to the database, data files were subject to a quality control process . The research team reviewed the data to verify correct synchronization of video to sensor data. Next, the research team selected several files from each hard drive 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, utilizing the triggers described below).

To identify valid SCEs within the established calendar dates for the baseline and intervention conditions (on a per-driver basis), the research team performed data reduction (to meet the A^2B^4 study design). SCEs of interest included crashes, near-crashes, crash-relevant conflicts, avoidable curb strikes, unavoidable curb strikes, and unintentional lane deviations. Researchers identified events of interest by scanning the data set for notable actions, such as hard braking, lane deviations, etc. To identify these actions, researchers set threshold values (i.e., "triggers") in MATLAB[i] code, based on previous heavy-truck naturalistic studies. The research team implemented four SCE triggers in the data reduction effort. Trigger values and thresholds were set low so that fewer valid events would be missed by the scan, as follows:

- **Longitudinal Acceleration.** Hard braking or sudden longitudinal acceleration less than or equal to −0.2g (deceleration), speed greater than 3.579 mi/h (5.76 km/h), and brake pedal status "depressed" (combined) for at least 0.1 second.
- **Lane Deviation.** Any time the truck aborts the lane line and returns to the same lane without making a lane change, such that the distance from the center of the lane to the outside of the lane line is greater than 55.118 inches (140 cm) with a sudden lateral acceleration greater than or equal to 0.2g or less than or equal to −0.2g and a speed greater than 24.606 mi/h (39.6 km/h) (combined) for at least 0.1 second.
- **Time-to-collision.** 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 less than or equal to 2 seconds, coupled with a range of less than or equal to 250 feet (76.2 m), a target speed greater than or equal to 5 mi/h (8.05 km/h), a yaw rate less than or equal to $|6°/s|$, and an azimuth of less than or equal to $|12°|$(combined) for at least 0.1 second.
- **Swerve.** A sudden "jerk" of the steering wheel to return the truck to its original position in the lane (S value greater than or equal to $2°/s^2$, and a speed ≥ to 5 mi/h [8.05 km/h]) (combined) for at least 0.1 second.

[i] MATLAB is a technical computing software.

Once these triggers were applied to the data set, each generated trigger was reviewed to determine if it was an event of interest (i.e., a valid event). For a trigger to be valid, the following criteria had to be met: recorded dynamic-motion values must have occurred; the trigger must have been verifiable in the video and other sensor data; and the trigger could be grouped into one of the previously noted event classifications (note: 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 braked hard for a stop sign, with no surrounding traffic). Invalid triggers were not analyzed any further. Experienced reductionists confirmed valid triggers and answered questions specific to each event, including conflict- and environment-related questions. For further validation, an experienced reductionist performed a second round of validation. The experienced reductionist used in the current study has extensive experience in naturalistic driving data reduction, specifically SCE validation and conflict scenario reduction. During the second round of validation, the experienced reductionist also noted any other driver behaviors or environmental variables occurring during the SCE (e.g., driver distractions, if present; assignment of fault in the SCE; weather or roadway characteristics, etc.).

3.2.4.3 Random Data Sampling to Assess Onboard Monitoring System Performance

The research team evaluated the performance of the OBMS by sampling a portion of all violations issued to the driver and comparing the potential infraction to what actually happened in the video. Researchers also randomly sampled the entire data set to ensure that the lack of a violation was also accurate (where violations were not recorded). This review, which assisted in validating the in-service accuracy of the OBMS, required the use of DAS video and kinematic data. For this purpose, the research team examined system performance by sampling data from all drivers during the intervention phase.

A meaningful data sampling approach was necessary given that the field study generated approximately 624,933 miles (1,005,733 km) of valid driver and collected violation data during the intervention period. Invalid data were removed if the driver was not a consented study participant or if the violation record was inconsistent due to DAS, OBMS, or DAS-to-OBMS interface malfunctions. Researchers randomly selected samples from violation data that had been recorded in real-time by the DAS during on-the-road data collection (for the 17 drivers with sufficient baseline and intervention OBMS data). Only speeding and seatbelt violations were sampled for validation in comparison with the OBMS. Researchers also randomly selected samples from periods of collection where violations were not recorded. Each sample selected for reduction was equal to a 1-millisecond timeframe (sync). A set of violation syncs and a set of non-violation syncs were selected. The data sample size was derived based on an estimated accuracy rate for the speed subsystem and seatbelt subsystem (separately). The speeding accuracy rate estimated for the validation test was 0.85. The seatbelt accuracy rate estimated for the validation test was 0.95. These estimates were established based on anecdotal evidence of driver feedback to the research team during on-the-road data collection. The resulting sample sizes per driver, and their respective accuracy rates, are available in Table 3. Note that the participant or driver numbers listed below range from 1 through 19, but driver numbers 6 and 8 have been removed for the accuracy assessment. An explanation for their removal is provided in the results section.

Table 3. Number of events sampled, proportional to collected driver mileage.

Driver No.	Intervention Mileage Proportion	Speeding Accuracy: Violation (est. 85%)	Speeding Accuracy: No Violation (est. 85%)	Seatbelt Accuracy: Violation (est. 95%)	Seatbelt Accuracy: No Violation (est. 95%)
1	5.9%	38	37	26	23
2	5.8%	45	44	24	27
3	4.6%	39	42	8	27
4	5.8%	32	65	27	28
5	7.2%	41	62	16	30
7	8.5%	66	71	33	36
9	4.6%	30	40	19	41
10	5.6%	43	51	6	28
11	7.8%	61	34	33	17
12	6.1%	37	39	21	31
13	6.0%	38	32	23	26
14	5.0%	46	28	21	21
15	7.2%	37	42	29	33
16	7.0%	49	48	30	25
17	7.6%	49	31	5	21
18	3.1%	23	15	24	17
19	2.3%	15	20	13	18
Total	**100.0%**	**689**	**701**	**358**	**449**

A relative number of violation syncs were selected from each driver's set of collected intervention violations using a random number generator (no time syncs were repeated). At each identified time sync, researchers evaluated a 16-second section of the video and the OBMS audible alert data. The OBMS configuration provided drivers with a 15-second delay (grace period) before recording a speeding or seatbelt violation. The OBMS was configured to provide at least two warning alerts to the driver during that grace period. In order to evaluate the speeding alerts, audio was played to listen for in-cab alerts and a posted speed sign was identified from the over-the-hood camera view. To evaluate the seatbelt alerts, audio was played to listen for in-cab alerts and the seatbelt worn status was identified from the driver-face camera.

A relative number of non-violation syncs were selected from periods of collected data that were at least 5 minutes apart from any recorded violation, to avoid interaction between driving scenarios with recorded violations and scenarios without recorded violations. Periods of speeding non-violations were randomly sampled from the collection where the minimum vehicle speed was 25 mi/h (40.2 km/h). Due to the nature of the collection, significant proportions of the collected data were known to be at speeds above 25 mi/h (40.2 km/h), but seatbelt violations were set to activate at vehicle speeds greater than 5 mi/h (8.0 km/h). Preliminary results of violations demonstrated that a majority of the seatbelt violations would occur at speeds lower than 25 mi/h (40.2 km/h). To align the periods of seatbelt non-violations randomly sampled from the collected vehicle miles, the sample was split into two groups:

- Greater than 5 mi/h (8.0 km/h), but less than 25 mi/h (40.2 km/h).
- At least 25 mi/h (40.2 km/h).

Reductionists observed these non-violations to obtain posted speed limits and confirm seatbelt worn status. However, the in-cab audible alerts could not be confirmed during these non-violation periods of time since the research team had informed participants that audio would only be observed around events containing recorded violations. The following questions are examples of what reductionists answered at each identified sync for each type of violation and non-violation:

- Does this sync contain a speeding violation?
  - If 'YES,' can you hear the audio alert in the cab? **(For violations only.)**
- If audio is present, describe the types of audio or noise present in the environment (e.g., radio, window is open, conversation).
- Observe the posted speed.
- Was Google Maps used?
- Speed limit sign observations (e.g., sign was unreadable, event occurred in a reduced-speed zone, driver changed roads during event).
- Record sync time of speed limit sign.
- Does this sync contain a seatbelt violation?
  - If 'YES,' can you hear the audio alert in the cab? **(For violations only.)**
- If audio is present, describe types of audio or noise present in the environment (e.g., radio, window is open, conversation).
- Is the driver in a parking lot at the beginning of the event?
- Is the driver wearing the seatbelt properly?
  - If 'NO,' describe how seatbelt is worn (e.g., not worn, behind driver, under arm).

After reductionists completed their evaluation of all violations and non-violations, the research team conducted a second round of validation to confirm or adjust the details occurring during the event. Events that occurred in reduced speed zones, such as construction, were removed from the system accuracy analysis since they could have short-term or long-term temporary speed signs posted (which would not necessarily be known by the OBMS maps). Additionally, violation events selected for review at points in time when the host vehicle had moved from one road to another without passing a posted speed sign, such as turning at an intersection, were also removed from the system accuracy analysis. In these instances, the reductionists reviewing the video would not have been able to confirm the posted road speed.

After each speed event was reduced and validated, a significant proportion required additional information to confirm the roadside posted speed sign. Equipment and scenario factors that limited the application of the DAS video for identifying speed signs included the following:

- Video compression.
- Oblique-angle view from host vehicle located in second or third inside lane.
- Obstruction in road, such as other vehicles being passed between the host vehicle and the posted speed limit signs.

In these cases, the posted speed limit sign's GPS coordinates were noted and identified in the online map software, Google Maps. In order for the online posted speed limit sign to be considered valid, the speed value had to be available and consistent at image dates before and after the date of the DAS event collection.

Queries on the vehicle parameters (i.e., vehicle speed and linear accelerations) were also conducted during this stage to compare to the data collected during reduction activities. Last, a senior researcher evaluated a sample of the reductionists' results by randomly selecting violation events for each driver. This step was a final confirmation of OBMS errors to eliminate any other possible causes before attributing those errors to the accuracy metrics. In addition, the research team also evaluated all false alarms and all missed detections found by reductionists for accuracy.

3.2.4.4 Fuel Usage

The research team evaluated the effect of the OBMS on fuel efficiency or fuel usage using vehicle measures collected by the DAS. The research team requested fuel economy data from the OBMS technology vendor at the end of data collection; however, the provided data were summarized per vehicle by month, were sporadic, and did not provide enough conclusive information. Furthermore, the summary carried data from multiple drivers per vehicle (i.e., not only consented participants). This unfiltered vehicle data would be insensitive to individual behaviors that may have changed between the baseline and intervention phases of the study. The research team had prepared a priori to capture multiple measures of fuel usage on the DASs, pulling data from the vehicles' J1939 CAN. One such measure was a flow rate of the fuel injectors. Although this measure is affected by injector wear over time, it does not carry other sources of error inherent in other combined estimates of fuel usage by distance, such as instantaneous or average fuel economy.

The fuel flow rate, in liters per hour, was collected at 10 hertz. Due to the tremendous volume of data captured across the 17 trucks from baseline through intervention, a strategic reduction method was needed. The research team decided, based on samples of fuel flow data, to split the measures by driver and between two groups over a consistent 1-month period. The prolonged recruitment period resulted in two groups of drivers at different stages of the study. One group of drivers had finished baseline data collection and was collecting intervention data, while the other group of drivers was just starting the baseline collection. Therefore, the fuel rate was analyzed between Group A (intervention phase) and Group B (baseline phase). The method of reducing the data collection to a 1-month period controlled for the differences in fuel usage inherent within each vehicle across a lengthy collection period. Drive files that were less than 10 minutes in duration were removed from the collection of files for analysis. The rates of fuel flow, which were collected 10 times per second, were averaged per minute of drive time. This reduction still left a tremendous number of fuel flow measures to analyze. Therefore, the average fuel flow per minute was also averaged across the entire drive file. The resulting measure for analysis in each phase, by group, was average fuel flow per driver's drive file with durations ranging from 10 minutes to 2 hours.

3.3 RESULTS

3.3.1 Participant Demographics

Twenty-seven drivers were recruited over the 11-month data collection period (2 females, 25 males). The research team collected baseline data from 25 drivers. Of these 25 drivers, 20 successfully completed their 2-month baseline condition participation. Of these 20 drivers, 19 contributed data in the intervention phase. Of these 19 drivers, 15 successfully completed the full 4-month intervention phase. One driver left the study based on a request to no longer have the vehicle monitored and recorded. The remaining attrition was due to fleet contract changes, driver employment changes, or driver health issues.

The 19 drivers (1 female, 18 males) who completed the baseline condition and at least some of the intervention condition reported both personal demographics and work experience during the screening process. Drivers had an average height of 69.5 inches (standard deviation [SD] = 2.6) and an average weight of 203.9 pounds. (SD =36.9). The majority of drivers reported an average build (63.16 percent) or large build (31.58 percent). Drivers reported working an average of 11.5 hours per shift (SD = 1.1) and 58.1 hours per week (SD = 13.6). They reported driving approximately 570.9 miles per shift, on average (SD = 79.7). Three drivers (15.79 percent) reported sharing a truck with others. All drivers stated they drove the truck alone a majority of the time. Drivers had worked, on average, 4.3 years (SD = 4.3) with the current company, with a minimum of 6 weeks and a maximum of 18.5 years. Among the 19 drivers, the age and total years of driving experience were collected for 15 drivers (these specific details were collected after data collection was complete, and some drivers could not be reached). Among those 15 drivers, the average age was 52.53 years (SD = 8.03) and the average years of CDL driving experience was 21.33 (SD = 11.27). Most drivers reported having experience with in-vehicle technologies (see Table 4).

Table 4. Participating drivers' self-reported data on in-vehicle technology use.

In-vehicle Technology	Number of Drivers Who Have Used the Technology	Percent of Drivers Who Have Used the Technology
Qualcomm	17	89.5%
Front Object Detection System	4	21.1%
Blind-spot Warning System	10	52.6%
Cell Phone (Voice/Texting)	16	84.2%
Electronic Onboard Recorder/Electronic Log Book	19	100.0%
Lane Departure Warning System	2	10.5%
OBMS	12	63.2%
GPS/Route Navigation	16	84.2%
Other In-vehicle Technologies	2	10.5%

3.3.2 Naturalistic Data Statistics

The research team collected 1,450,459 miles (2,334,289 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.) After all collected data were filtered for driver identification, and each participant's baseline and intervention phases were identified across the 19 drivers, a total of 1,274,452 miles (2,051,033 km) remained for reduction—a distance equivalent to 458 transcontinental trips between New York, NY, and Los Angeles, CA.

As the research team was cleaning and auditing the reduced data, it became apparent that two of the drivers who had been included in the SCE reduction should not be included in the analyses of system accuracy or effects on safety between baseline and intervention. An OBMS in one vehicle demonstrated intermittent performance communicating with the DAS during data collection. Further inspection of the data demonstrated that the OBMS appeared to be experiencing system-wide malfunctions in that vehicle. A second driver was active only in the intervention phase for 2 weeks due to taking medical leave; therefore, the research team thought it necessary to remove these drivers' (identified as participating driver numbers 6 and 8) baseline phase and limited intervention phase data from the analyses. The total mileage (collected across the baseline and intervention phases) remaining for analysis across the 17 drivers was 1,196,146 miles (1,925,011 km).

3.3.3 Onboard Monitoring System Accuracy Assessment

The research team performed data reduction to identify the accuracy of OBMS events in terms of driver performance violations during the intervention phase. The OBMS reports speeding, seatbelt, and aggressive driving violations. Events captured by the OBMS (e.g., speeding) were available in a database variable called "violations," received by the DAS from the OBMS in-vehicle auxiliary data port. In contrast, speeding events that may not have been captured by the OBMS were identified by a randomly sampled drive file.

3.3.3.1 Speeding

Speeding events were validated by observation of posted speed signs on synchronous video through the forward-facing camera near the event timeframe. Reductionists observed non-typical road scenarios that would make the posted speed data unreliable, such as construction zones. Those events were not included in the evaluation data set. Reductionists also checked posted speed signs to determine if the event occurred within the United States or Canada. For events occurring in Canada, the speeds were converted from kilometers per hour to miles per hour. Reductionists also made note of signs that displayed truck speed limits (which varied from speed limits for light vehicles). In some cases, the posted speed sign could not be identified from the forward-facing camera due to the video compression frame rate, viewing distance across multiple lanes (i.e., the vehicle was in a passing lane and the speed sign was positioned on the side of the road), or another tractor-trailer drove between the host vehicle and the speed sign. In those cases, the posted speed signs may have been validated by inserting the latitude and longitude at the DAS sync into Google Maps. When attempting to validate an event with information from Google Maps, a reductionist confirmed that: 1) map dates were available before and after the date of event collection for that particular road or latitude/longitude coordinates, and 2) that the speed limit posted for both dates was consistent. Approximately 18 percent (127) of the 689 violations that were validated required the use of Google Maps.

Of the 689 sampled speeding violations, 593 (86.07 percent) were issued correctly (speeding observed, violation recorded). The remaining 96 (13.93 percent) were issued incorrectly (no speeding observed, violation recorded). The 95-percent confidence interval for the correct speeding violation rate was [83.48 percent, 88.65 percent], suggesting with 95-percent certainty that the true mean of speeding violation rates is between 83.48 and 88.65 percent. The distribution of speed in the violation sample is displayed in Figure 8, below. A large proportion (83.0 percent) of speeding violations occurred between 60 and 85 mi/h. The speed distribution for all sampled speeding violations ranged from 30.5 mi/h (49.1 km/h) to 84.0 mi/h (135.2 km/h).

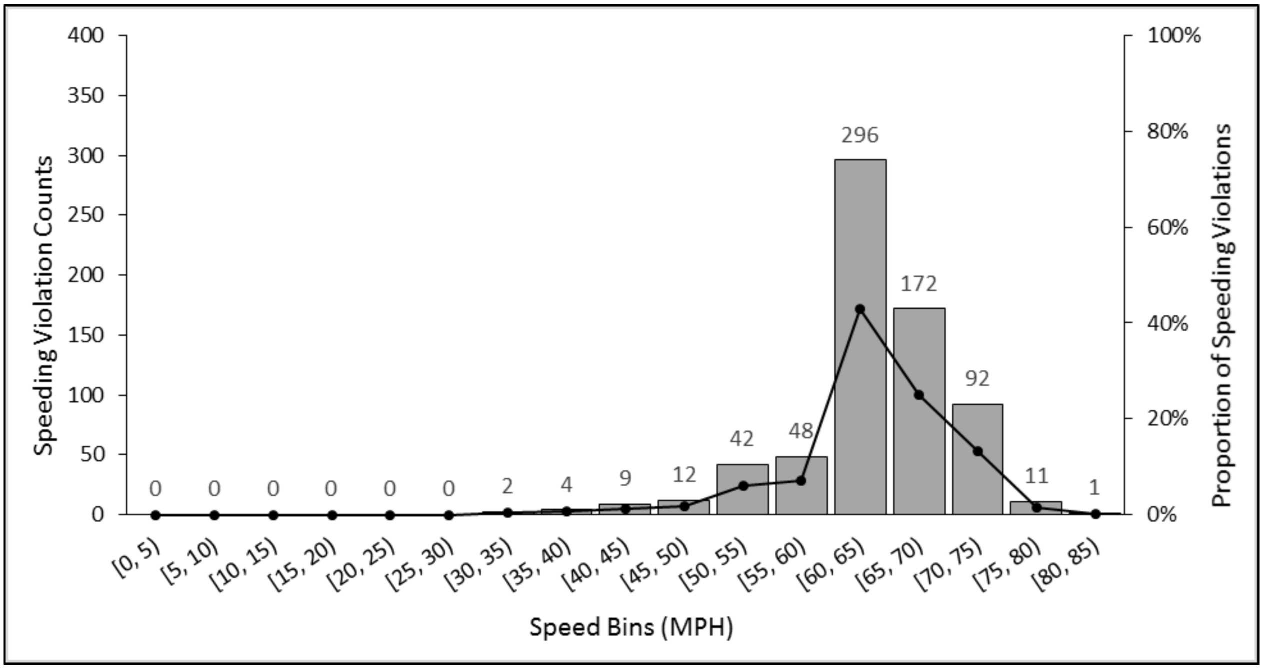

Figure 8. Chart. Distribution of speed in speeding violation sample.

The non-violation sample used to evaluate speeding system accuracy included 701 non-violation periods. Speeding non-violations included 674 (96.15 percent) correct non-violations (no speeding observed, no violation recorded) and 27 (3.85 percent) incorrect non-violations (speeding observed, no violation recorded). The 95-percent confidence interval for the correct speeding non-violation rate was [94.72 percent, 97.57 percent], suggesting with 95-percent certainty that the true mean of speeding non-violation rates is between 94.72 and 97.57 percent. The speed distribution across the speeding non-violations is graphically displayed in Figure 9. The speed during non-violations ranged from about 25 mi/h (40.2 km/h) to 77 mi/h (123.9 km/h), with the majority (77.2 percent) of non-violations falling in the 60–70 mi/h (69.5–112.7 km/h) range.

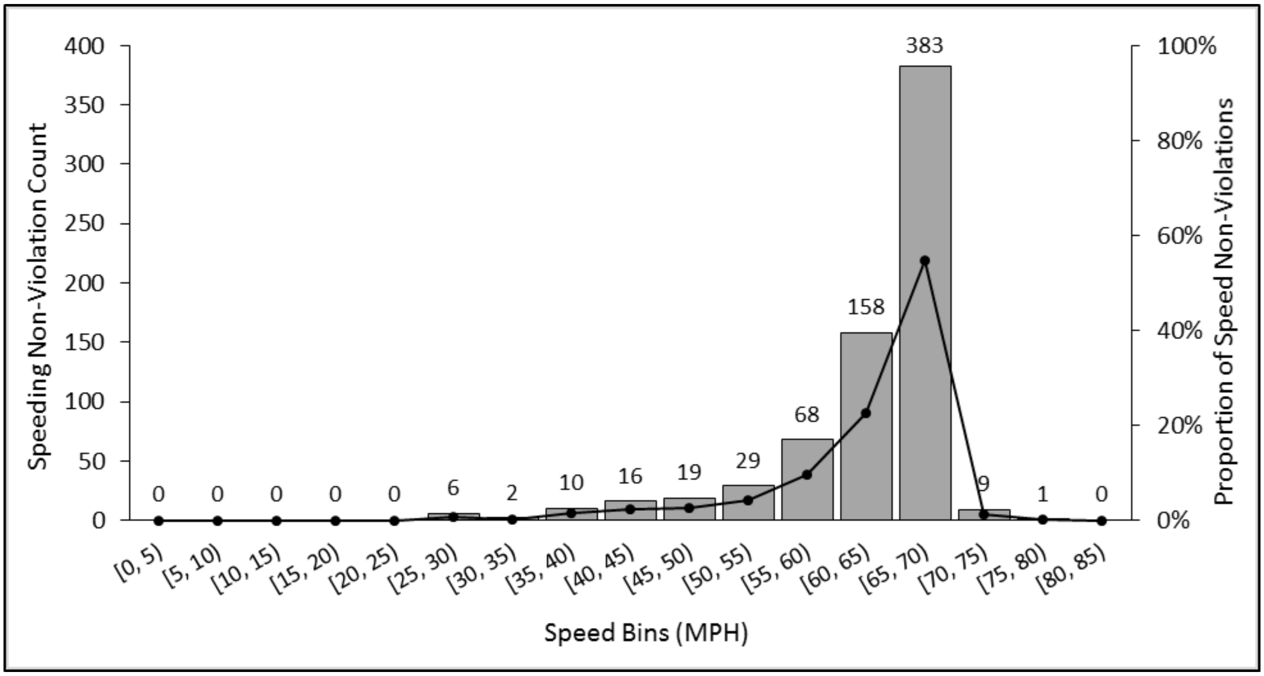

Figure 9. Chart. Distribution of speed in speeding non-violation sample.

3.3.3.2 Seatbelt

Seatbelt events were validated on synchronous video through a driver-facing camera at the event timeframe. Reductionists made note if the vehicle was located in a parking lot during the seatbelt event. Reductionists recorded if the seatbelt appeared latched or not. The OBMS relied on a magnetic switch mounted to the buckle and tongue to determine if the seatbelt was being worn. Reductionists also noted when the seatbelt was not properly worn over the left clavicle (shoulder) in the event that the driver might be attempting to cheat the OBMS by sitting on the belt or wearing it under the shoulder while latched.

All 358 sampled seatbelt violations were correctly issued (seatbelt not buckled properly, violation recorded). The 95-percent confidence interval for the seatbelt correct violation rate was (99.86 percent, 100.00 percent), suggesting with 95-percent certainty that the true mean of seatbelt correct violation rates is between 99.86 and 100.00 percent. Of the 358 sampled seatbelt violations, 303 or 84.6 percent occurred while driving in parking lots. The distribution of speed in the seatbelt violation sample is displayed in Figure 10. The majority of seatbelt violations (93.3 percent) occurred while driving less than15 mi/h (24.1 km/h). The speed distribution for all sampled seatbelt violations ranged from 1.6 mi/h (2.6 km/h) to just over 68 mi/h (109.4 km/h).

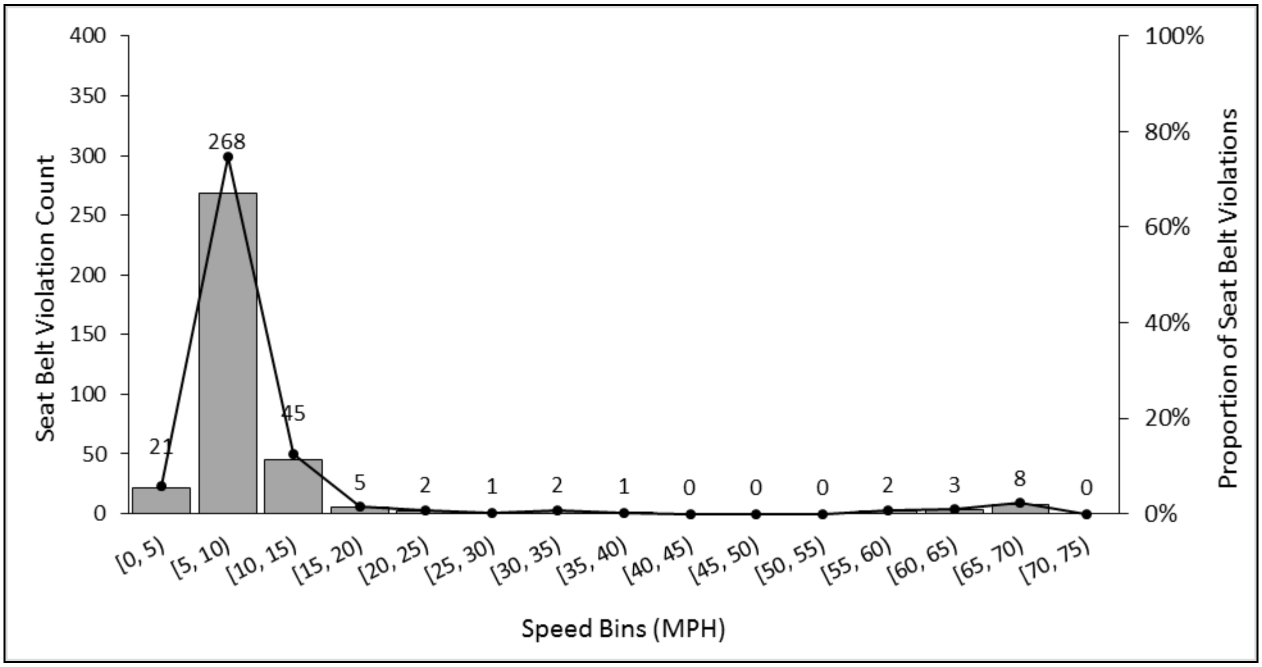

Figure 10. Chart. Distribution of speed in seatbelt violation sample.

The non-violation sample used to evaluate seatbelt violations included 449 non-violation periods, all of which were correct (all observations showed drivers wearing seatbelts). The 9-percent confidence interval for the seatbelt correct non-violation rate was [99.89 percent, 100.00 percent], suggesting with 95-percent certainty that the true mean of seatbelt correct non-violation rates is between 99.89 and 100.00 percent. The non-violation sample included 24 (5.3 percent) observations in parking lots. The speed distribution across the seatbelt non-violations is graphically displayed in Figure 11. The speed during non-violations ranged from just over 5 mi/h (8.0 km/h) to about 73 mi/h (117.5 km/h), with the majority of non-violations falling in the 65–70 mi/h (104.7 to 112.7 km/h) range.

During the assessment of the non-violation sample, the research team also observed whether drivers were properly wearing their seatbelts. With this type of system, it would be possible for the driver to latch the seatbelt buckle and sit on the shoulder belt or the lap belt or both. Across the 449 non-violation periods sampled, 33 (7.3 percent) were observed to have some deficiency in proper wear across the lap and left shoulder (clavicle). All of those cases were categorized as "loose shoulder belt."

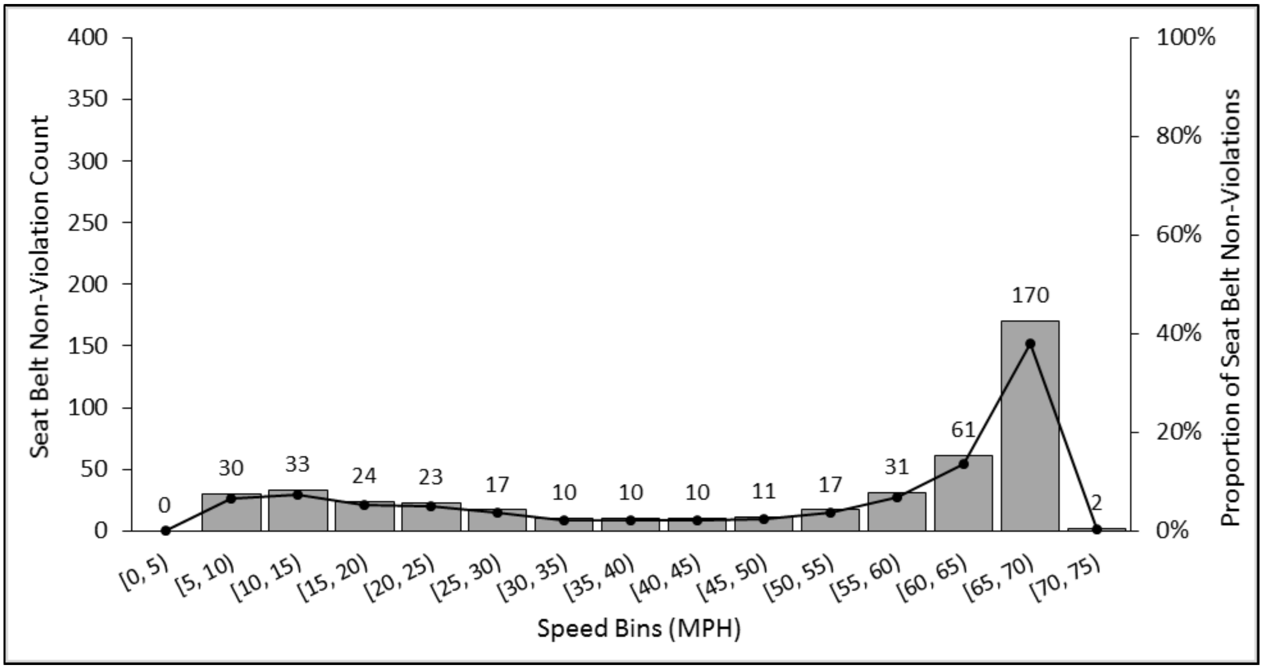

Figure 11. Chart. Distribution of speed in seatbelt non-violation sample.

3.3.3.3 Aggressive Driving

Aggressive driving violations were very infrequent. During the approximately 1.2 million miles of (analyzed) driving data, 30 distinct aggressive driving violations were recorded by the DAS from the OBMS. Because this evaluation was designed to serve as an observation of the OBMS capabilities and the relationship between the OBMS and the fleet during revenue-producing operations, the fleet worked with the OBMS vendor to calibrate the sensitivity of the measures of aggressive driving preferred by the fleet. Due to this fleet/vendor arrangement and the limited number of violations, the research team decided not to assess the system's accuracy in the aggressive driving category. Comparisons were attempted between the OBMS and synchronous DAS accelerometer sensor data; however, rates of acceleration between the two different system sensors varied in amplitude and axis (*x*, *y*, *z*), while the peaks were not synchronous.

Table 5 lists the types of aggressive driving violations recorded for each participating driver who had at least one occurrence. Driver 16 had the highest number of "hard brake" violations, and driver 17 had the highest number of "hard turn" violations. A short description of the scenario and vehicle actions is provided in Table 6 and Table 7. Table 8 summarizes the vehicle speeds at the time of the sync at which each aggressive driving violation occurred. The g-forces related to the violations by each type are summarized in Table 9. These g-forces were measured by the OBMS sensors.

Table 5. The frequency of aggressive driving violations per driver.

Driver #	Frequency for Hard Brake (dvX) [n = 11]	Frequency for Hard Turn (dvY) [n = 18]	Frequency for Hard Bump (dvZ) [n = 1]
1	1	0	0
3	1	1	0
9	0	2	0
11	0	0	1
12	0	2	0
13	2	1	0
14	1	3	0
15	1	1	0
16	4	1	0
17	1	7	0

Table 6. Scenario description for driver with most frequent hard-brake violations.

Driver 16: Hard Brake Scenarios
1. Driver in right lane that is merging. Driver brakes hard to avoid hitting another vehicle.
2. Driver slowed to take an exit ramp at the last minute.
3. Driver slows rapidly at a traffic signal that has just turned red.
4. Driver is on interstate traveling slower than flow of traffic and eventually comes to a complete stop on shoulder for unknown reason.

Table 7. Scenario description for driver with most frequent hard-turn violations.

Driver 17 Hard Turn Scenarios
1. Driver stops at a traffic light and then turns left.
2. Driver is moving slowly and turns left at a traffic light.
3. Driver slows and turns left at a non-light intersection onto secondary road.
4. Driver makes sharp left turn at non-standard intersection.
5. Driver is stopped and makes sharp left turn at same non-light intersection as scenario "3."
6. Driver is stopped and makes sharp left turn at same non-light intersection as scenario "3."
7. Driver slows and makes left turn on a non-light intersection onto secondary road.

Table 8. Vehicle speeds (mi/h) summarized by aggressive violation type.

Violation Type	Mean Vehicle Speed at Violation	Minimum Vehicle Speed at Violation	Maximum Vehicle Speed at Violation
Hard Brake (n = 11)	28.6	4.2	54.7
Hard Turn (n = 18)	18.8	10.0	40.5
Hard Bump (n = 1)	61.3	61.3	61.3

Table 9. Vehicle g-forces summarized by aggressive violation type.

Violation Type	Mean g-Force	Minimum g-Force	Maximum g-Force
Hard Brake (dvX) [n = 11]	0.53	0.45	0.62
Hard Turn (dvY) [n = 18]	0.43	0.40	0.61
Hard Bump (dvZ) [n = 1]	0.37	0.37	0.37

3.3.3.4 In-cab Audible Feedback

During the intervention phase, the OBMS provided drivers with in-cab audible alerts (verbal, in real-time) prior to or at the time of the speeding, seatbelt, or aggressive-driving violation, in order to help them correct their driving performance. In the cases of speeding and seatbelt events, the system gave the drivers a 15-second grace period to adjust their vehicle speed or buckle their seatbelt before a violation was recorded. The DAS was continuously collecting audio, which was allowed based on consent by the participating drivers. However, the research team was only allowed to observe the audio at timeframes identified by the OBMS system variable recorded by the link to the DAS. Therefore, in-cab audible alerts were only being validated when the OBMS had recorded a related violation. The collected audio data contained a lot of background noise and interference, including wind noise, in-cab radio, and driver conversations. Therefore, sampled events in which the background noise completely masked the OBMS audible alert were removed from the data set for analysis.

Each violation was assessed for clarity or presence of the audio alert in the truck cab. Table 10 shows the distribution of audio status in seatbelt and speeding alerts. The audio was clear in a majority of the violations (95 percent of the seatbelt violations and 77 percent of the speeding violations); however, not all sampled violations with clear audio had an audible alert (12 percent of seatbelt violations and 4 percent of speeding violations had clear audio and no audible alert). The presence of an audible alert was undeterminable (either due to unclear audio or complete silence) in 5 percent of seatbelt violations and 23 percent of speeding violations.

Table 10. Audio status distribution in seatbelt and speeding violations.

Alert Audio Status	Seatbelt Violation Count	Percent of Seatbelt Violations	Speeding Violations Count	Percent of Speeding Violations
Clear Audio, Alert Heard	297	83%	505	73%
Clear Audio, No Alert Heard	43	12%	26	4%
Unclear Audio	11	3%	109	16%
Complete Silence	7	2%	49	7%
Total	**358**	**100%**	**689**	**100%**

3.3.4 Safety Evaluation (Safety-critical Event Analysis)

During this study, 311 valid SCEs were identified during the reduction process. The distribution of SCEs in the baseline and intervention phases is displayed in Table 11. The baseline phase included 153 SCEs and the intervention phase included 158 SCEs. The table also includes the counts and proportion for all SCE types.

Table 11. Distribution of SCEs in the baseline and intervention phases.

SCE Type	Baseline Phase (Number)	Baseline Phase (Percent)	Intervention Phase (Number)	Intervention Phase (Percent)
Crash	3	2.0%	4	2.5%
Near-crash	24	15.7%	20	12.7%
Crash-relevant Conflict	39	25.5%	55	34.8%
Curb Strike: Avoidable	11	7.2%	29	18.4%
Curb Strike: Unavoidable	21	13.7%	20	12.7%
Unintentional Lane Deviation	55	35.9%	30	19.0%
Total	**153**	**100.0%**	**158**	**100.0%**

3.3.4.1 Safety-critical Event Analysis: Driver at Fault, Driver Not at Fault, Other Fault, and Unknown

Following the process explained in the previous section, researchers completed data reduction to identify valid SCEs. SCEs of interest included crashes, near-crashes, crash-relevant conflicts, avoidable curb strikes, unavoidable curb strikes, and unintentional lane deviations. Events of interest were obtained by scanning the collected vehicle data for notable actions. To identify these actions, threshold values in MATLAB code were set based on previous heavy-truck naturalistic studies. Validation of these events through video data reduction was completed by trained and experienced crash reductionists.

For each driver, the rate of SCEs per 10,000 vehicle miles traveled (VMT) was calculated for both phases of the study. In Figure 12, the per-driver baseline and intervention SCE rates are plotted. Driver 18 had no SCEs in the baseline phase of the study and driver 9 had no SCEs in the intervention phase of the study.

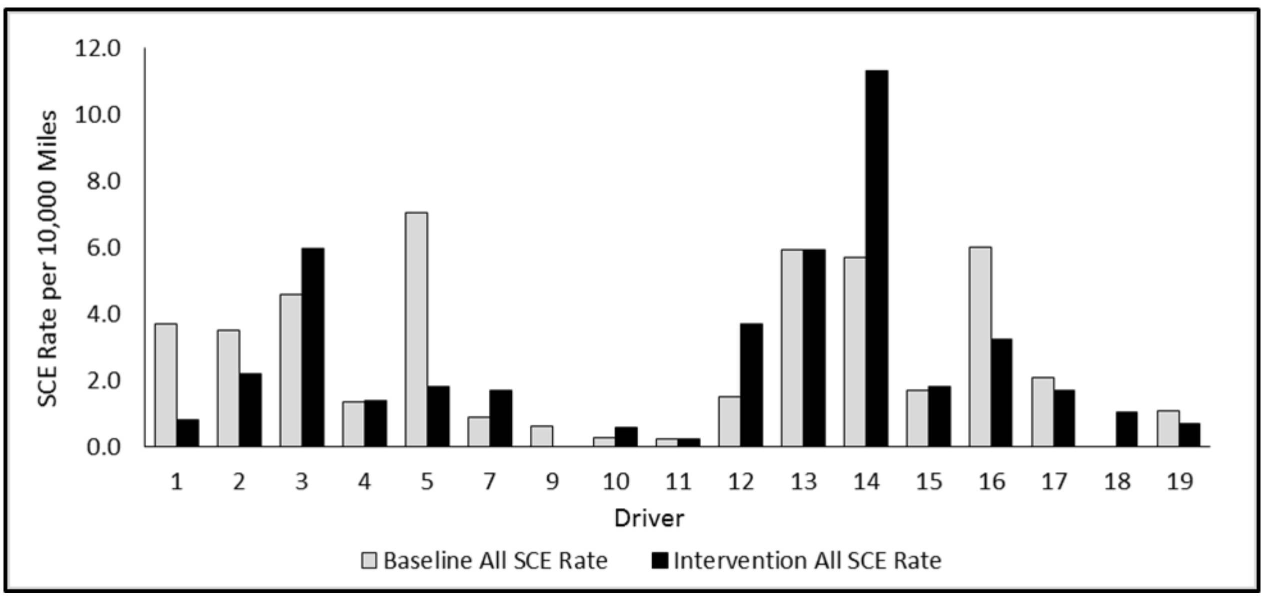

Figure 12. Chart. Baseline and intervention rates of all SCEs per 10,000 VMT for each participating driver with valid data.

During the baseline phase, these 17 drivers drove a total of 571,213 miles. The mean rate of all SCEs per 10,000 VMT during the baseline phase was 2.7 (SD = 2.4). During the intervention phase, the drivers drove a total of 624,933 miles. The mean rate of SCEs per 10,000 VMT during the intervention phase was 2.6 (SD = 2.85). A paired sample, one-sided *t*-test found that the mean rate of SCEs per 10,000 VMT during the intervention phase was not significantly lower than the mean rate of SCEs per 10,000 VMT during the baseline phase, $\alpha = 0.05$, $t(16) = 0.2$, $p = 0.4124$.

The next analysis only considered the following SCE types in the SCE rate: crash (C), near-crash (NC), crash-relevant conflict (CRC), and unintentional lane deviation (ULD). These events are also referred to as “safety-critical event–excluding curb strike” (SCE-XCS). The mean rate of these SCE-XCSs per 10,000 VMT during the baseline phase was 2.1 (SD = 2.0). The mean rate of these SCE-XCSs per 10,000 VMT during the intervention phase was 1.7 (SD = 1.4). Figure 13 shows the rate of SCE-XCSs per 10,000 VMT per driver in the baseline and intervention phases. A paired sample, one-sided *t*-test found that the mean rate of SCE-XCSs per 10,000 VMT during the intervention phase was not significantly lower than the mean rate of SCE-XCSs per 10,000 VMT during the baseline phase, $\alpha = 0.05$, $t(16) = 1.01$, $p = 0.1647$.

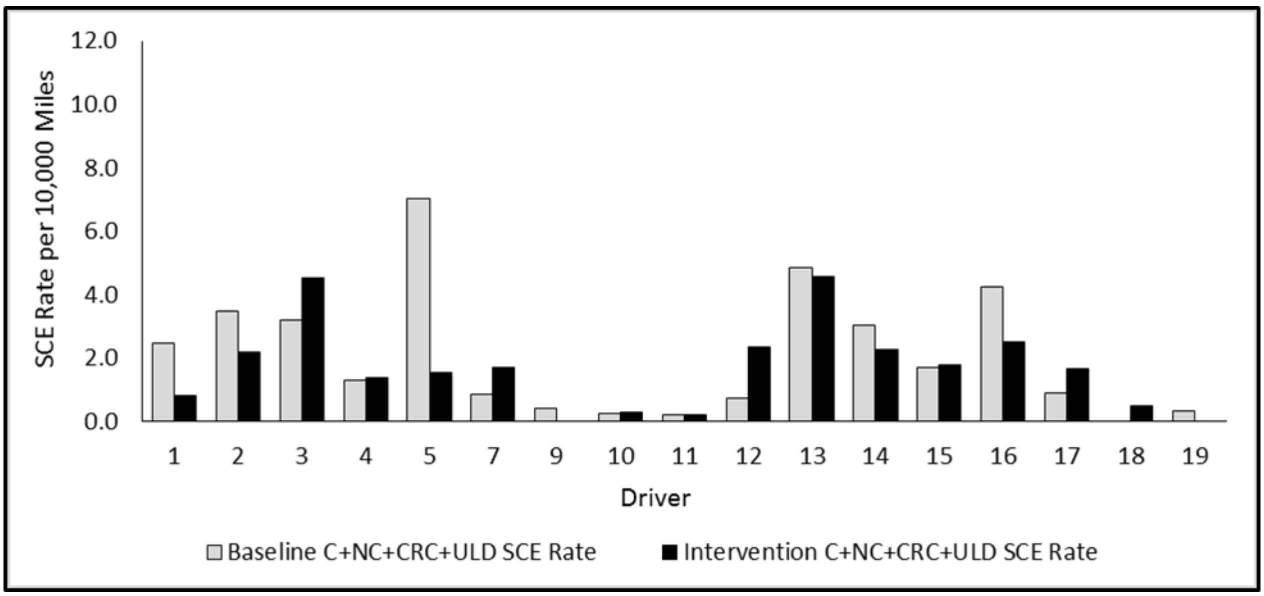

Figure 13. Chart. Baseline and intervention rates of crash, near-crash, crash-relevant conflict, and unintentional lane deviation SCEs per 10,000 VMT for each participating driver with valid data.

3.3.4.2 Safety-critical Event Analysis: Driver at Fault

During video reduction, researchers assessed fault for each SCE. The options for fault were: subject vehicle (participating driver’s vehicle); other vehicle, animal, pedestrian, or pedalcyclist; no fault—object or environmental; or unknown. Only subject-vehicle at-fault SCE-XCSs were used in the next analysis.

For at-fault SCE-XCSs, the baseline mean rate of SCE-XCSs per 10,000 VMT was 1.4 (SD = 1.4). The intervention mean rate for these at-fault types was 1.1 (SD = 1.1). Figure 14 shows the rate of at-fault SCE-XCSs per 10,000 VMT per driver in the baseline and intervention phases. A paired sample, one-sided *t*-test found the mean rate of at-fault SCE-XCSs per 10,000 VMT during the intervention phase was not significantly lower than the mean rate of SCE-XCSs per 10,000 VMT during the baseline phase, $\alpha = 0.05$, $t(16) = 1.45$, $p = 0.0831$.

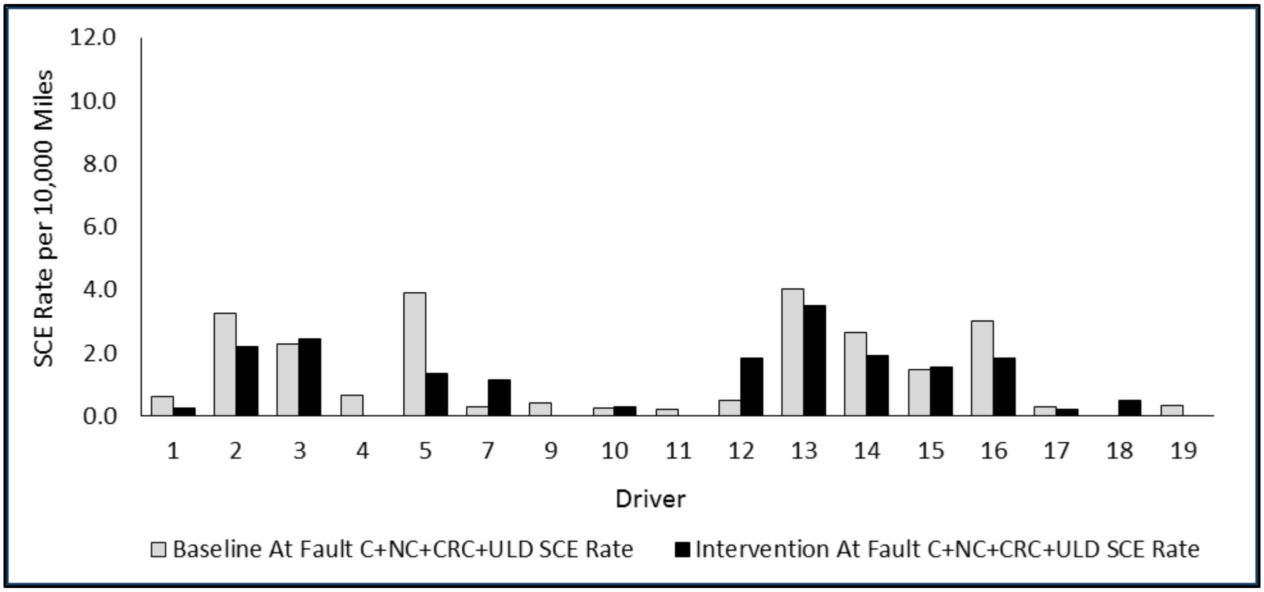

Figure 14. Chart. Baseline and intervention rates of participating driver at-fault crash, near-crash, crash-relevant conflict, and unintentional lane deviation SCEs per 10,000 VMT for each participating driver with valid data.

Although the research team did not find a statistically significant decrease in SCE rate from the baseline to the intervention phase, that does not necessarily mean that the drivers experienced a true static SCE rate. In Figure 12, Figure 13, and Figure 14, it can be seen that several drivers had a decrease in SCE rate from baseline to intervention, while others had an increase in SCE rate. Table 12 shows the number of drivers and average difference in SCE rates (intervention—baseline) for drivers with a decreased SCE rate and for those with an increased SCE rate. Calculations were completed for rate of all SCEs, rate of SCEs excluding curb strikes, and rate of at-fault SCEs excluding curb strikes. The sample of drivers was almost evenly split between those with a decreased rate and those with an increased rate for the rate of all SCEs and the rate of SCEs excluding curb strikes. Nearly two-thirds of the drivers had a decreased at-fault SCE rate excluding curb strikes from baseline to intervention.

Table 12. Number of drivers and average difference in SCE rate (intervention − baseline) for participants with a decreased or increased SCE rate.

SCEs Included in SCE Rate Analysis	Number of Drivers with Decreased SCE Rate	Average Difference in Decreased SCE Rate	Number of Drivers with Increased SCE Rate	Average Difference in Increased SCE Rate
All SCEs	8	-1.71	9	1.28
SCEs Excluding Curb Strikes (SCE-XCSs)	9	-1.33	8	0.66
At-fault SCE-XCSs	11	-0.74	6	0.49

3.3.4.3 Speeding Activity

As discussed previously, FMCSA's *Large Truck Crash Causation Study* found that among CMV crashes where the CMV driver was at fault, the large majority of critical reasons for the crash (87.3 percent) were assigned to driver error. Of those factors assigned to driver error, 38 percent were attributed to decision errors (e.g., speeding per conditions).

The evaluated OBMS provided the driver with an audible warning when the vehicle exceeded the posted speed limit by 5 mi/h (8.0 km/h) or more. The built-in, proprietary OBMS map software relied on pre-set, posted speed limit references for the specific road being traveled and measured for each vehicle. The warning was an audible alert to drivers, telling them to check their speed. As mentioned previously, this initial audible alert was repeated every 10 seconds after the criteria were exceeded and continued until the vehicle speed was reduced below the posted speed limit plus 5 mi/h (8.0 km/h). If the driver failed to comply within 15 seconds, the OBMS recorded a violation that was communicated to the OBMS database and the fleet. For this study's purposes, drivers only received feedback on audible alerts and violations related to speeding during the intervention phase.

To validate the occurrence of a speeding violation, the researchers sampled and reviewed the video data recorded prior to the violation. This was done to determine if the posted speed limit on the road being traveled matched the OBMS's referenced speed limit. According to the sample, the OBMS was 86 percent accurate at reporting speeding status during the intervention phase, as discussed in the section on OBMS accuracy (see Section 3.3.3.1). Therefore, on occasion, the OBMS reported that drivers were speeding (according to fleet-selected criteria) when they were not actually speeding—approximately 14 percent of the time (as sampled). The following results cover all recorded speeding violations from the baseline through the intervention phase.

For each driver, researchers calculated rates of speeding violations per 1,000 miles driven for both the baseline and the intervention period. Drivers averaged 29.01 violations per 1,000 miles in the baseline period (SD = 17.32) and 14.65 violations per 1,000 miles in the intervention period (SD = 13.11). Figure 15 compares the speeding violation rates, per driver, in both study periods. Sequential speeding violations were not recorded if the driver maintained the speeding behavior. Repeated violations that did occur were either due to the driver decelerating below the speeding threshold and then accelerating again to go beyond the threshold of the posted speed limit plus 5 mi/h (8.0 km/h), or the driver speeding beyond the posted speed limit plus 15 mi/h (24.1 km/h), which was not separated in the analysis. Speeding events were examined by collection file to examine violations that occurred within a short period of time. A collection file represents vehicle departure to vehicle arrival, or a maximum 2-hour driving period. Of the 22,106 combined baseline and intervention speeding violations collected, approximately 92.3 percent (20,402) occurred within the same collection file as at least one other speeding violation. Of the violations that occurred within the same collection file, 84 percent occurred within a 10-minute period from the previous speeding violation among all drivers. The average amount of time between speeding violations in the same file was 6.8 minutes.

Of the 17 drivers with speeding violation data, 14 drivers (82.35 percent) had a decreased speeding violation rate in the intervention period. The other three drivers (17.65 percent) had an increased speeding violation rate in the intervention period. The average difference in speeding violation rates (intervention—baseline) was 14.36 fewer violations per 1,000 miles (SD = 14.00). The baseline and intervention mileage, violation counts, and rates can be found in Table 13. A paired, one-sided *t*-test of the speeding violation rate differences (intervention—baseline) showed a statistically significant decrease ($t = -4.23$, degrees of freedom [df] = 16, $p = 0.0003$).

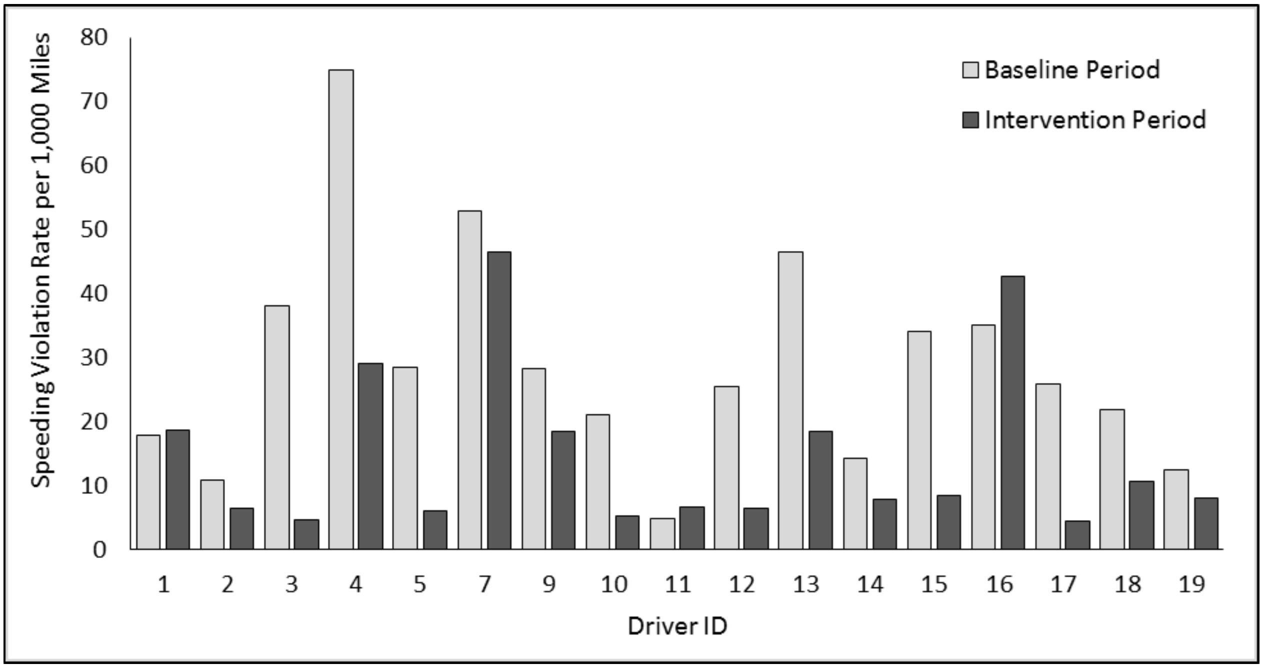

Figure 15. Chart. Speeding violation rates, per driver, in the baseline and intervention study periods.

Table 13. Baseline and intervention mileage and speeding violation data for all participating drivers.

Driver ID	Baseline Miles (1,000 mile units)	Intervention Miles (1,000 mile units)	Baseline Speeding Violation Count	Intervention Speeding Violation Count	Baseline Rate of Speeding Violations per 1,000 Miles	Intervention Rate of Speeding Violations per 1,000 Miles	Difference in Violation Rate (Intervention—Baseline)
1	16.24	36.94	290	688	17.86	18.62	0.77
2	45.78	36.45	502	238	10.97	6.53	−4.44
3	21.97	28.60	838	136	38.15	4.76	−33.39
4	30.31	36.13	2,273	1,050	75.00	29.06	−45.94
5	25.56	44.92	727	274	28.44	6.10	−22.34
7	10.72	52.99	567	2,460	52.88	46.43	−6.46
9	43.59	28.45	1,233	524	28.29	18.42	−9.87
10	34.19	30.02	719	157	21.03	5.23	−15.80
11	28.66	49.01	142	328	4.95	6.69	1.74
12	39.94	38.00	1,016	249	25.44	6.55	−18.88
13	23.45	37.22	1,090	690	46.48	18.54	−27.94
14	17.54	30.98	250	242	14.25	7.81	−6.44
15	27.50	44.93	940	376	34.18	8.37	−25.81
16	22.07	43.69	775	1,865	35.12	42.69	7.57
17	16.25	47.41	421	215	25.90	4.54	−21.37
18	13.60	19.57	297	208	21.84	10.63	−11.21
19	16.78	14.55	208	118	12.39	8.11	−4.29

The speeding violation rate per 1,000 miles was calculated for each driver for 2-week windows within the intervention period (e.g., days 1–14 of the intervention period, days 15–28 of the intervention period, etc.) Not every driver had data for every 2-week window due to time off from driving or dropping out of the study. Figure 16 shows the average speeding violation rate per 1,000 miles over time. There was a sharp decrease in the average speeding violation rate from the baseline period to the first 2 weeks of the intervention (from 29.01 to 18.37, a 37 percent decrease in speeding violations per 1,000 miles, with 17 drivers in each of the comparison phases). A Wilcoxon signed-rank test of the differences indicated a significantly lower median of speeding violation rates in the first 2 weeks of the intervention than in the baseline period ($W = 55.5$, $p = 0.0067$). The speeding violation rate continued to decrease until the fourth 2-week window (days 43–56). From days 57 through 126, the speeding violation rate increased, although it remained lower than the baseline speeding violation rate. The ninth 2-week window (days 113–126) had the highest speeding violation rate during the intervention phase (22.58 speeding violations per 1,000 miles, with 7 drivers with data for this window). However, a Wilcoxon signed-rank test of the differences in the baseline phase and the ninth 2-week window speeding violation rates was not significant, thus indicating that there is no difference in the medians of speeding violation rates for drivers active in the ninth 2-week window compared to their baseline rates ($W = 10.0$, $p = 0.1094$).

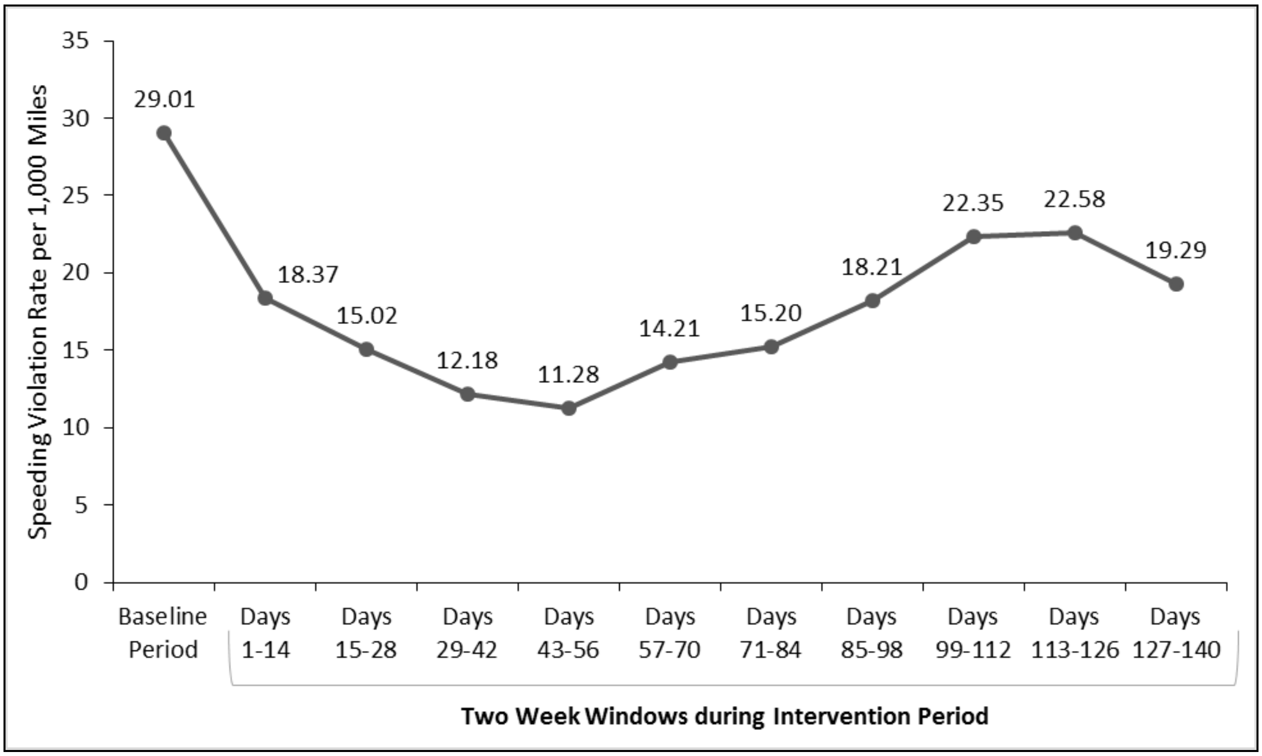

Figure 16. Line chart. Speeding violation rate per 1,000 miles over time in study (baseline period and 2-week intervention period windows).

Table 14. Speeding violation rate per 1,000 miles over time in study for all drivers (baseline period and 2-week intervention period windows).

Driver ID	Baseline Period	Days 1-14	Days 15-28	Days 29-42	Days 43-56	Days 57-70	Days 71-84	Days 85-98	Days 99-112	Days 113-126	Days 127-140
1	17.86	1.96	1.43	11.99	17.06	30.28	21.37	24.92	41.31	N/A	N/A
2	10.97	28.23	5.32	10.94	4.12	5.20	3.64	3.73	8.78	N/A	N/A
3	38.15	9.01	1.37	1.89	4.14	6.50	5.15	4.63	6.73	N/A	N/A
4	75.00	78.66	9.74	1.97	3.54	15.90	30.42	55.58	48.60	N/A	N/A
5	28.44	4.68	10.91	4.75	3.07	2.80	4.04	6.67	4.82	15.00	N/A
7	52.88	49.03	54.91	60.02	45.65	60.86	25.24	39.45	51.78	44.31	38.35
9	28.29	8.95	18.41	20.65	16.84	18.60	25.71	N/A	35.54	N/A	N/A
10	21.03	0.00	N/A	8.10	3.08	4.18	14.83	1.63	3.09	N/A	N/A
11	4.95	7.99	8.00	6.71	6.95	3.26	5.21	5.24	3.35	11.60	10.62
12	25.44	5.49	5.37	6.07	1.96	5.89	N/A	N/A	6.86	19.52	6.67
13	46.48	7.21	23.41	6.45	13.02	19.42	14.66	34.23	34.75	18.86	15.92
14	14.25	8.25	11.74	10.97	3.72	8.19	2.68	0.46	28.06	N/A	8.37
15	34.18	30.35	18.97	18.24	1.66	6.96	0.00	0.00	0.00	N/A	0.00
16	35.12	45.86	38.24	11.79	39.33	32.77	57.37	59.75	59.38	40.88	61.36
17	25.90	11.98	0.18	1.03	5.11	0.61	10.13	3.74	0.63	7.90	13.05
18	21.84	9.04	25.55	N/A	N/A	5.86	7.58	14.90	23.89	N/A	N/A
19	12.39	5.51	6.81	13.37	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	**29.01**	**18.37**	**15.02**	**12.18**	**11.28**	**14.21**	**15.20**	**18.21**	**22.35**	**22.58**	**19.29**

3.3.5 Seatbelt Usage

Seatbelt usage in commercial trucking is an area of concern. As discussed in the introduction, sampled seatbelt usage has increased in recent years to 84 percent; however, there are still seatbelt usage trends that indicate a continuing problem. The evaluated OBMS provided feedback to the driver when the seatbelt was not latched and the vehicle was traveling faster than 5 mi/h (8.0 km/h). This warning was an audible alert to the driver to fasten the seatbelt. The initial alert occurred when the criteria was exceeded and repeated every 10 seconds until the seatbelt has been latched. If the driver failed to comply within 15 seconds, the OBMS recorded a violation, which was communicated to the OBMS database and the fleet. For this study's purposes, the drivers only received feedback on seatbelt usage during the intervention period.

To validate the occurrence of a seatbelt violation, the researchers sampled and reviewed the video recorded during the violation to confirm whether the driver was wearing the seatbelt. The OBMS's level of accuracy for the seatbelt latched and unlatched status during intervention was very high (100 percent as sampled), as discussed in Section 3.3.3.2. Therefore, the seatbelt usage trends from the baseline to the intervention phase (below) can be understood to represent scenarios where the record of the seatbelt latched status was highly consistent with the driver's state of seatbelt usage.

For each driver, the research team calculated rates of seatbelt violations per 1,000 miles driven, for baseline and intervention periods. Drivers averaged 11.10 violations per 1,000 miles in the baseline period (SD = 5.44) and 3.41 violations per 1,000 miles in the intervention period (SD = 3.92). Figure 17 compares the violation rates, per driver, in both study periods. Every driver had a decreased seatbelt violation rate in the intervention period. The average difference in seatbelt violation rates (intervention—baseline) was 7.69 less violations per 1,000 miles (SD = 5.12). The baseline and intervention mileage, violation counts, and rates are shown in Table 15.

A paired *t*-test of the seatbelt violation rate differences (intervention—baseline) showed a statistically significant decrease ($t = -6.19$, df = 16, $p < 0.0001$).

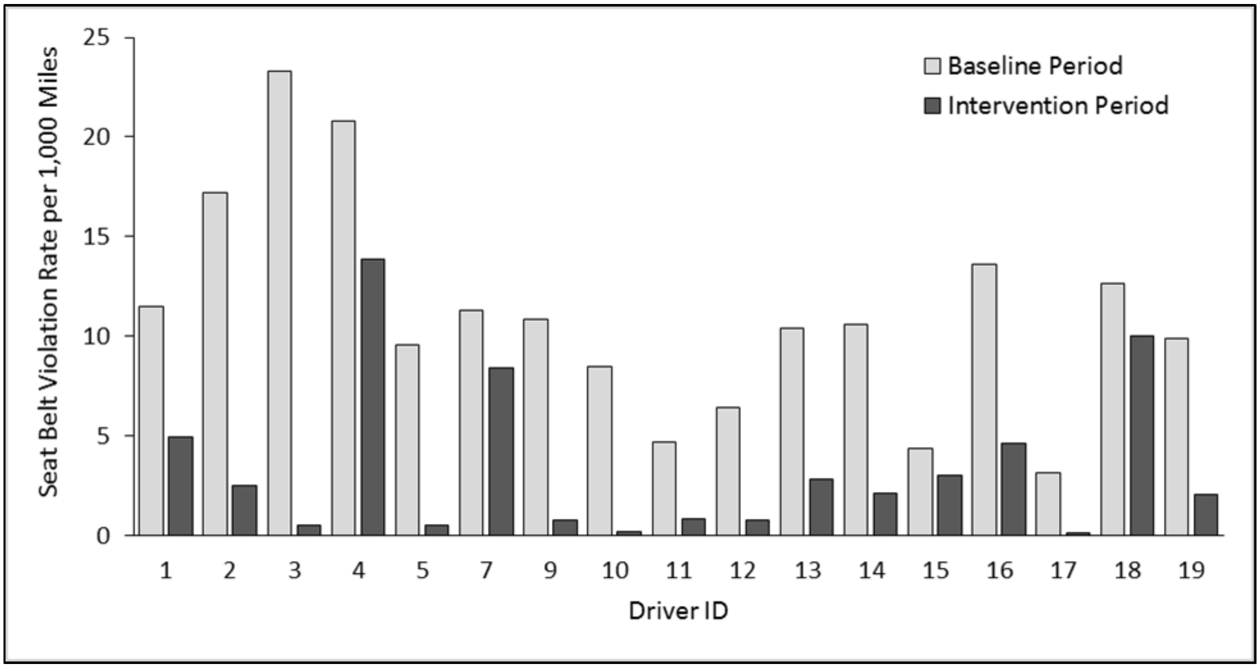

Figure 17. Bar chart. Seatbelt violation rates, per driver, in the baseline and intervention periods.

Table 15. Baseline and intervention mileage and seatbelt violation data for all participating drivers.

Driver ID	Baseline Miles (1,000 Mile Units)	Intervention Miles (1,000 Mile Units)	Baseline Seatbelt Violation Count	Intervention Seatbelt Violation Count	Baseline Rate of Seatbelt Violations per 1,000 Miles	Intervention Rate of Seatbelt Violations per 1,000 Miles	Difference in Violation Rate (Intervention—Baseline)
1	16.24	36.94	187	182	11.51	4.93	−6.59
2	45.78	36.45	788	90	17.21	2.47	−14.74
3	21.97	28.60	512	15	23.31	0.52	−22.78
4	30.31	36.13	630	501	20.79	13.87	−6.92
5	25.56	44.92	245	24	9.59	0.53	−9.05
7	10.72	52.99	121	446	11.29	8.42	−2.87
9	43.59	28.45	473	22	10.85	0.77	−10.08
10	34.19	35.11	290	6	8.48	0.17	−8.31
11	28.66	49.01	134	41	4.68	0.84	−3.84
12	39.94	38.00	257	28	6.43	0.74	−5.70
13	23.45	37.22	244	104	10.40	2.79	−7.61
14	17.54	30.98	186	66	10.60	2.13	−8.47
15	27.50	44.93	119	135	4.33	3.00	−1.32
16	22.07	43.69	300	203	13.59	4.65	−8.95
17	16.25	47.41	51	6	3.14	0.13	−3.01
18	13.60	19.57	172	196	12.65	10.02	−2.63
19	16.78	14.55	166	30	9.89	2.06	−7.83

The seatbelt violation rate per 1,000 miles was calculated for each driver for 2-week windows within the intervention period (e.g., days 1–14 of the intervention period, days 15–28 of the intervention period, etc.) Not every driver had data for each 2-week window due to time off from driving or dropping out of the study. Figure 18 shows the average seatbelt violation rate per 1,000 miles over time. There was a sharp decrease in the average seatbelt violation rate from the baseline period to the first 2 weeks of the intervention (from 11.10 to 4.88, a 56 percent decrease in seatbelt violations per 1,000 miles, with 17 drivers in each of the comparison periods). A Wilcoxon signed-rank test of the differences indicated a significantly lower median of seatbelt violations in the first 2 weeks of the intervention than in the baseline period ($W = 74.5$, $p < 0.0001$). The last 2-week window, days 127–140, had the lowest average seatbelt violation rate (1.87 seatbelt violations per 1,000 miles, with 8 drivers with data for this window). This 2-week window was also found to be significantly different than the baseline period values for the same drivers ($W = 18.0$, $p = 0.0078$).

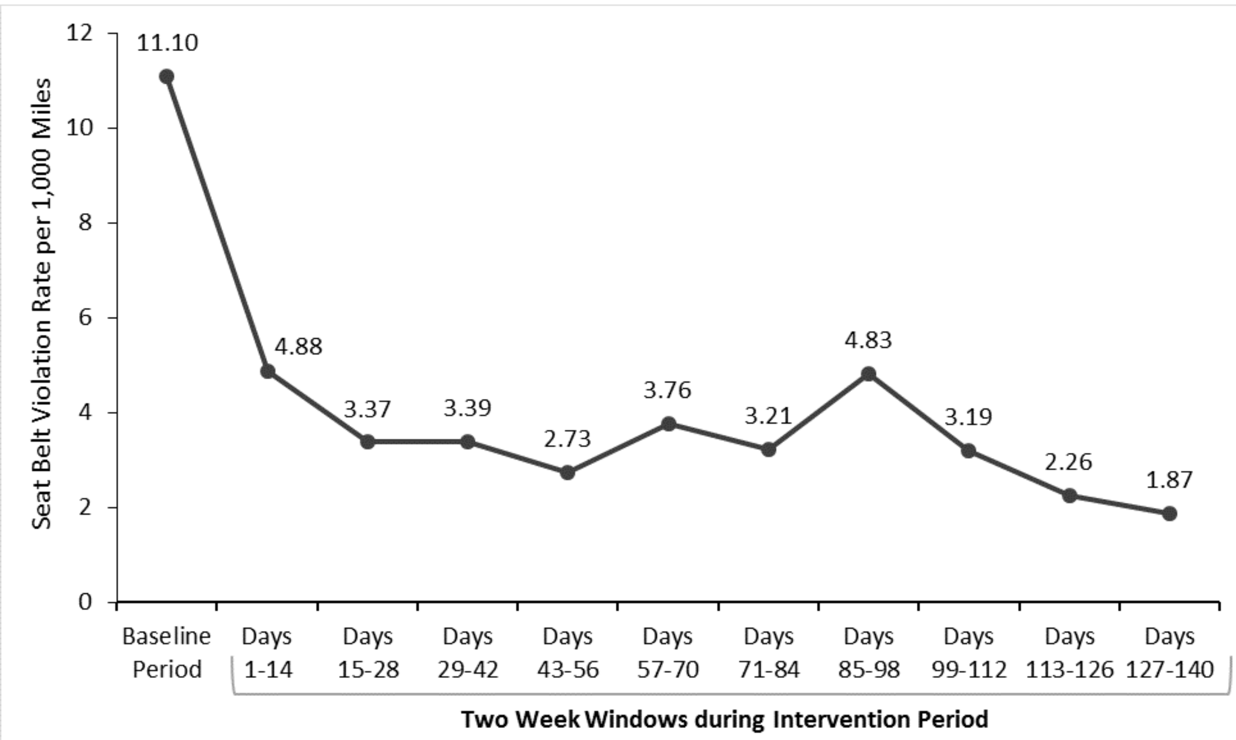

Figure 18. Chart. Seatbelt violation rate per 1,000 miles over time in study (baseline period and 2-week intervention period windows).

Table 16. Seatbelt violation rate per 1,000 miles over time in study for all drivers (baseline period and 2-week intervention period windows).

Driver ID	Baseline Period	Days 1-14	Days 15-28	Days 29-42	Days 43-56	Days 57-70	Days 71-84	Days 85-98	Days 99-112	Days 113-126	Days 127-140
1	11.51	1.42	2.15	2.48	7.48	4.33	4.35	15.61	4.25	N/A	N/A
2	17.21	10.76	3.49	3.18	0.77	2.17	3.07	1.42	1.53	N/A	N/A
3	23.31	3.86	0.46	0.00	0.00	0.57	0.00	0.00	0.00	N/A	N/A
4	20.79	18.44	12.93	12.19	9.02	23.30	12.99	13.80	8.33	N/A	N/A
5	9.59	1.62	2.82	0.19	0.00	0.00	0.21	0.35	0.00	0.57	N/A
7	11.29	9.57	8.37	17.64	7.83	6.73	8.74	8.86	6.21	5.58	3.84
9	10.85	0.80	1.17	1.21	0.23	0.21	0.74	N/A	2.03	N/A	N/A
10	8.48	1.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A
11	4.68	1.28	2.38	2.30	0.18	0.20	0.87	0.00	0.53	0.70	0.00
12	6.43	0.32	1.07	0.79	0.16	2.52	N/A	N/A	0.53	0.91	0.45
13	10.40	0.86	1.16	2.93	4.42	4.31	2.88	3.89	3.29	2.80	1.71
14	10.60	2.17	2.76	2.74	2.48	2.12	0.82	0.46	3.30	N/A	2.95
15	4.33	4.24	3.26	3.61	2.91	2.53	2.98	3.14	2.33	N/A	2.03
16	13.59	8.98	4.25	3.04	5.40	4.10	2.90	4.03	4.86	5.25	3.99
17	3.14	0.61	0.00	0.17	0.00	0.00	0.25	0.17	0.21	0.00	0.00
18	12.65	13.35	9.41	N/A	N/A	7.11	7.41	15.87	13.57	N/A	N/A
19	11.51	1.42	2.15	2.48	7.48	4.33	4.35	15.61	4.25	N/A	N/A
Average	**11.10**	**4.88**	**3.37**	**3.39**	**2.73**	**3.76**	**3.21**	**4.83**	**3.19**	**2.26**	**1.87**

3.3.6 Qualitative Analysis (Driver and Manager Acceptance)

3.3.6.1 Driver Pre-study and Post-study Questionnaires

Due to the Paperwork Reduction Act, there are limitations on the number of study participants who can complete surveys and/or questionnaires (no more than nine participants are allowed to complete questionnaires/surveys). Therefore, only seven drivers and two safety managers were selected to complete questionnaires for this study. The seven randomly selected drivers completed questionnaires containing rating scales and open-ended questions. Two safety managers were recruited and completed the post-study interview. The questionnaires and interviews can be found in Appendices D and E.

The questionnaires had two purposes:

- To determine the baseline self-reported driving behaviors (see Table 17).
- To determine the participants' expectations of the OBMS before implementation and their level of acceptance after experiencing the system in their vehicle for at least 6 months total (see Table 18).

Table 17. Pre-study driving behavior questionnaire frequency of responses.

Question: In the past 12 months while driving, how often did you…	Never (percent)	Never (count)	Rarely (percent)	Rarely (count)	Sometimes (percent)	Sometimes (count)	Often (percent)	Often (count)
Run red lights?	71.4%	5	28.6%	2	0.0%	0	0.0%	0
Change lanes suddenly to get ahead of traffic?	28.6%	2	42.9%	3	28.6%	2	0.0%	0
Go through a stop sign without stopping?	100.0%	7	0.0%	0	0.0%	0	0.0%	0
Speed for the thrill of it?	71.4%	5	28.6%	2	0.0%	0	0.0%	0
Not yield the right of way?	57.1%	4	42.9%	3	0.0%	0	0.0%	0
Make illegal turns?	42.9%	3	57.1%	4	0.0%	0	0.0%	0
Follow a car very closely or “tailgate”?	57.1%	4	28.6%	2	14.3%	1	0.0%	0
Take more risks because you were in a hurry?	71.4%	5	14.3%	1	14.3%	1	0.0%	0
Drive at normal speed during bad conditions, like road construction, rain, ice or snow?	50.0%	3	16.7%	1	16.7%	1	16.7%	1
Pass other cars on the right side on the shoulder of the road?	71.4%	5	14.3%	1	14.3%	1	0.0%	0
Accelerate when a traffic light turned yellow?	0.0%	0	85.7%	1	14.3%	1	0.0%	0
Cut off, honk or yell at other drivers who drive too slowly to cut you off?	42.9%	3	28.6%	2	28.6%	2	0.0%	0
Do other things while driving, like use cell phone, eat or drink, or smoke cigarettes?	0.0%	0	14.3%	1	42.9%	3	42.9%	3
Take your eyes off the road to adjust the CD player or pick something up from the floor?	28.6%	2	57.1%	4	14.3%	1	0.0%	0
Not check your mirrors when passing another car or merging onto the highway?	71.4%	5	0.0%	0	0.0%	0	28.6%	2
Drive 10-20 mi/h over the limit?	42.9%	3	57.1%	4	0.0%	0	0.0%	0
Drive more than 20 mi/h over the limit?	85.7%	6	14.3%	1	0.0%	0	0.0%	0
Not yield to pedestrians?	71.4%	5	0.0%	0	0.0%	0	28.6%	2
Drive without wearing a safety belt?	71.4%	5	14.3%	1	0.0%	0	14.3%	1
Turn without signaling?	71.4%	5	28.6%	2	0.0%	0	0.0%	0
Pass where visibility was obscured?	85.7%	6	14.3%	1	0.0%	0	0.0%	0
Not make a full stop at a stop sign?	57.1%	4	42.9%	3	0.0%	0	0.0%	0

Table 18. Comparison of pre-study and post-study questionnaire responses for the driver's opinion of the technology.

Question	Pre-study Mean Response	Pre-study Median Response	Post-study Mean Response	Post-study Median Response	Wilcoxon Signed-Rank *W* Statistic for *Post—Pre*	*p* value
How much do you like the idea of having the waySmart on your truck? *Extremely Dislike It (1) to Extremely Like it (7)*	0.5	4.0	4.4	4.5	-1.5	0.8125
I think the way Smart is… *Useless (1) to Useful (7)*	5.3	5.0	5.3	6.0	4.0	0.5781
Unpleasant (1) to Pleasant (7)	4.5	5.0	5.1	6.0	3.5	0.5000
Bad (1) to Good (7)	4.8	5.0	5.0	5.5	2.5	0.6875
Annoying (1) to Nice (7)	4.6	5.0	4.8	5.0	3.5	0.5625
Ineffective (1) to Effective (7)	5.3	5.0	5.0	6.0	0.5	0.9844
Irritating (1) to Likeable (7)	4.7	4.8	4.5	4.5	0.0	1.0000
Worthless (1) to Assisting (7)	4.9	5.8	5.0	6.0	2.5	0.6875
Undesirable (1) to Desirable (7)	4.9	5.3	5.1	6.0	3.0	0.5938
Sleep-inducing (1) to Raising Alertness (7)	4.9	5.3	5.8	6.0	5.0	0.3438

The pre-study and post-study questionnaires included a free-response section where drivers could share likes and dislikes about the system. In the pre-study questionnaire, the drivers indicated that their anticipated likes included improving driver safety and skills and providing information or evidence. Driver comments included:

- "Hopefully it will be useful down the road or in the future."
- "Help drivers with driving."
- "Show driver their mistakes."
- "Think it will help out in the long run."
- "Will help keep my alertness on high."

Conversely, the drivers' anticipated dislikes were few, but focused on being watched. Responses included:

- "Someone watching me."
- "Tell and show all."

As reported in the post-study questionnaire, the drivers' actual likes included increased seatbelt use and improved awareness. Comments included:

- "Reminds you to wear your seatbelt."
- "Made me a better driver."
- "Keeps me more alert to what's going on around me."
- "Alerted you on your speed, seatbelt violation."
- "Make sure you use your seatbelt all the time."
- "Kept you from speeding a lot."
- "Kept me informed of seatbelt use."
- "Made me more aware of my speed and surroundings."

The drivers' actual dislikes were concerns about the speed limit set for the seatbelt violation and the accuracy of the speed limits for the speeding violations. The comments related to actual dislikes included:

- "Need to up the speed to 6 over instead of 5 miles per hour."
- "Talks too much about speed."
- "Check your speed."
- "Would not have correct speed limits."
- "Would go off in the middle of the night with safety checks."

- “Seatbelt limit is set at 5 mi/h.”
- “Seatbelt warning set at too low of a speed, should be at least 20 mi/h, verbal warning while moving in yard, 5 mi/h = too slow.”

In the post-study questionnaire, drivers were also asked about their experience using the system. All drivers reported adjusting to the system within 1 month. The questions, with mean and median responses, are shown in Table 19. For all questions, mean and median responses were near neutral to slightly above neutral.

Table 19. Post-study questionnaire responses on waySmart device use.

Question	Mean Response	SD	Median Response
How does your driving performance with waySmart compare to your driving performance without waySmart? *Scale: Extremely Worse (1) to Extremely Better (7)*	4.68	0.80	5.00
How much do you agree with the statement: "I would like to have waySmart in my truck" *Scale: Strongly Disagree (1) to Strongly Agree (7)*	5.18	1.42	5.50
How much do you agree with the statement: "waySmart has made me a safer driver." *Scale: Strongly Disagree (1) to Strongly Agree (7)*	5.39	1.57	6.00
How much do you agree with the statement: "waySmart encourages regular seatbelt use." *Scale: Strongly Disagree (1) to Strongly Agree (7)*	5.89	0.96	6.00
How much do you agree with the statement: "waySmart effectively alerts me about speeding." *Scale: Strongly Disagree (1) to Strongly Agree (7)*	5.18	1.37	5.00
How much do you agree with the statement: "waySmart has improved my fuel efficiency" *Scale: Strongly Disagree (1) to Strongly Agree (7)*	5.25	1.25	5.00
How much do you agree with the statement: "waySmart is easy to use." *Scale: Strongly Disagree (1) to Strongly Agree (7)*	5.96	1.05	6.00
How uncomfortable is the glare from the display when you are driving at night and looking forward down the road? *Scale: Extremely Uncomfortable (1) to Extremely Comfortable (7)*	4.82	1.01	5.00
How uncomfortable is the glare from the display when you are driving at night and looking directly at the light? *Scale: Extremely Uncomfortable (1) to Extremely Comfortable (7)*	4.54	1.21	5.00

3.3.6.2 Fleet Manager/Staff Interviews

The research team conducted post-study interviews with a fleet manager and a dispatcher to identify any safety benefits the fleet may have recognized from the OBMS, 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. The fleet manager for the participating fleet was responsible for the purchase and upkeep of all fleet tractors, trailers, and associated equipment, including technology such as the OBMS. The dispatcher assigned drivers to loads and was involved in the OBMS driver-coaching elements of this study.

The participating manager believed that the OBMS would change drivers' on-road driving behaviors because: 1) it would provide constant monitoring and prompting to correct hazardous driving habits, and 2) the drivers were aware that a company official could review any hazardous driving incidents. The fleet manager did not think that the type of route (e.g., long-haul, regional, or short-haul) would affect the efficacy of the OBMS, although the participating fleet was primarily long-haul.

When asked how the drivers initially reacted to the OBMS, the fleet manager commented that there were some "big brother" concerns that quickly vanished when drivers understood that the company was only seeing incidents of bad driving behavior, call-ins, or accidents. The fleet manager also recalled an occasion when the application of a previous OBMS with video data was helpful in understanding how to assign fault after a serious accident. Because of that OBMS data, the fleet driver was exculpated of fault. After this incident, the fleet drivers had a more positive view of OBMS technology.

When asked about their impression of the performance of the OBMS, the fleet manager felt that the OBMS improved drivers' seatbelt usage and speeding behaviors the most. The key area of improvement cited by both the fleet manager and the dispatcher was the inability of the OBMS to distinguish between posted speed limits for cars and trucks. According to the interviewees, this seemed to occur only in specific States (e.g., Indiana and Wyoming). The dispatcher stated that drivers found these erroneous violations to be distracting in the beginning of the study.

The fleet manager and dispatcher indicated that the fleet currently provides a broad range of driver training (e.g., new driver training, fuel economy training, Smith System, etc.), and that the introduction of the OBMS would not drastically affect the training currently in place.

A primary factor for implementing new technologies is the estimate of return on investment provided by the technology vendor. The fleet manager felt it would be difficult to justify the OBMS economically because the system requires the time of a manager to coach drivers. The fleet manager did state that Federal or insurance incentives would indeed influence decisions on the adoption of the OBMS, as well as any reduction in liability costs to the company. Despite these economic concerns, the manager believed that the OBMS would be useful in the fleet.

3.3.7 Fuel Usage Results

The resulting measure of fuel usage for analysis was split between baseline and intervention phases by two groups of drivers. The fuel flow, in liters per hour, was averaged per driver's drive file with durations ranging from 10 minutes up to 2 hours. The distribution of fuel rate per drive file is described in Table 20 and Figure 19. Among the baseline group files, 2,833 files (50 percent) were 10 minutes or longer. Among the intervention group files, 3,325 files (56 percent) were 10 minutes or longer. The average fuel rate was 25.69 liters per hour for baseline files (SD = 10.40) and 26.81 liters per hour for intervention files (SD = 8.98). The median fuel rate was 27.84 liters per hour for baseline files and 28.31 liters per hour for intervention files. Figure 19 illustrates the similar average fuel rate distributions between the baseline and intervention groups. The baseline group had a slightly higher percentage of files with an average fuel rate of

0–5 liters per hour than the intervention phase (6.32 percent of baseline files and 1.62 percent of intervention files).

Table 20. Descriptive statistics of file average fuel rate (liters per hour) for files 10 minutes or longer in duration, from sampled time frame, with fuel rate data in baseline and intervention group phases.

Study Group Phase	Number of Files	Average File Fuel Rate (Liters/hr)	Standard Deviation (Liters/hr)	25th %tile (Liters/hr)	Median, 50th %tile (Liters/hr)	75th %tile (Liters/hr)
Baseline	2,833	25.69	10.40	19.78	27.84	33.00
Intervention	3,325	26.81	8.98	21.41	28.31	33.00

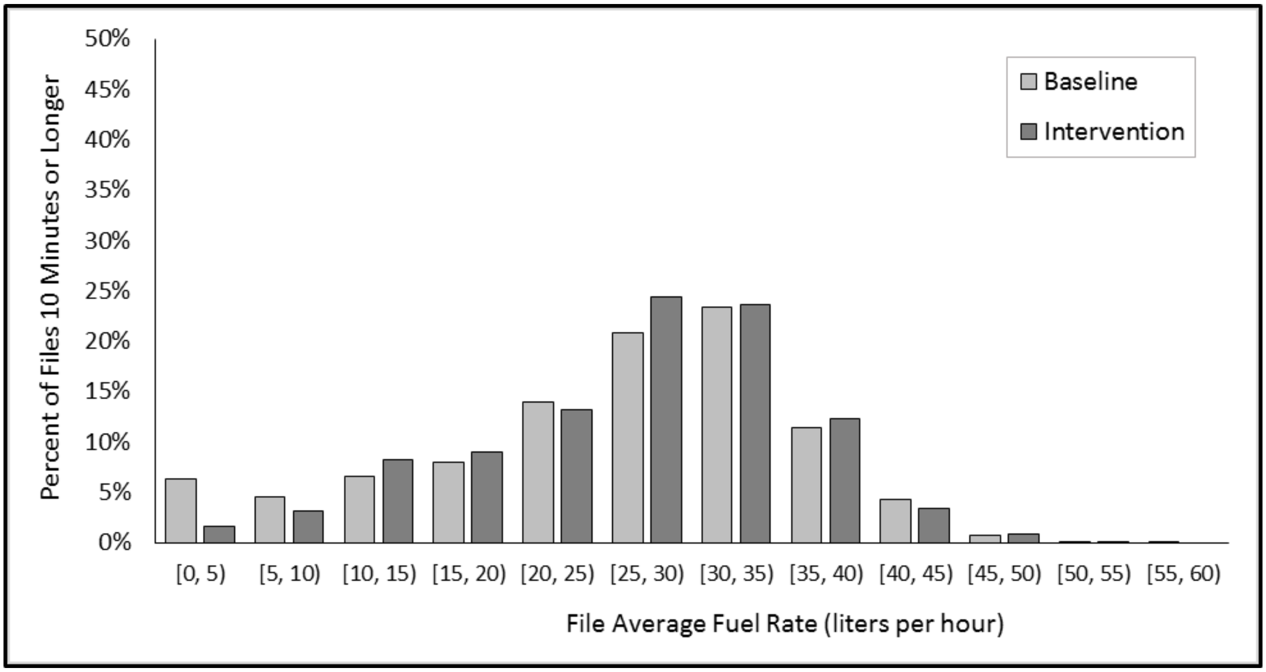

Figure 19. Chart. Distribution of file average fuel rate (liters per hour) for files 10 minutes or longer in duration, from sampled time frame, with fuel rate data in baseline and intervention group phases.

A generalized, linear-mixed model with file identification (ID) as a random effect was used to model the differences in file average fuel rate by group phase for files 10 minutes or longer in duration. The group phase was modeled as an indicator variable (baseline and intervention as “1” and “0,” respectively). The resulting model follows:

$$\text{Fuel rate} = 26.8095 - 1.1222 \times \text{Study Phase}$$

The difference in file average intervention group minus baseline group fuel rates (estimated difference in least square means of −1.1222, standard error [SE] = 0.25) was found significant at $\alpha = 0.05$ $t(6{,}156) = -4.54$, $p < 0.0001$. This means that the fuel usage for the group of drivers in the intervention phase was worse than the fuel usage for the group of drivers in the baseline phase. These results are inconclusive as to what effect the OBMS had on fuel efficiency.

4. CONCLUSIONS

The OBMS provided drivers with real-time feedback about their driving behavior to encourage safe operations. The following conclusions demonstrate the steps that the research team took to capture and measure the OBMS interface with the drivers and fleets. Some opportunities for improvement are discussed in the recommendations section.

4.1 SYSTEM PERFORMANCE

The performance and reliability of the OBMS was evaluated based on controlled testing on the Virginia Smart Road and on field testing in a revenue-producing fleet. The controlled testing evaluated activation and DAS collection of OBMS-generated data. The field testing evaluated accuracy of the OBMS based on the sampling of collected OBMS, vehicle, and DAS sensor data.

4.1.1 Controlled Testing

The purposes of the controlled testing were to determine: 1) how the OBMS interfaced with the DAS, and 2) how the OBMS features operated on a test CMV. The collection of audible alerts and violations were confirmed on the DASs. The controlled testing demonstrated appropriate activation of violations for seatbelt usage. The controlled testing demonstrated some limitations of the OBMS with regard to speeding violations on secondary roads and highways with short deviations in speed limit and activation of aggressive driving violations.

4.1.2 Field Testing

The research team sampled violations and periods of non-violations to estimate the level of accuracy that the OBMS provided to the fleet regarding driver performance. Based on driver feedback to the research team during data collection, the research team anticipated that the speeding violations would be correct approximately 85 percent of the time, and that the seatbelt violations would be correct approximately 95 percent of the time. Therefore, violation and non-violation periods were sampled from the collected data proportional to these estimates and proportional to the vehicle miles collected for each vehicle.

According to the speeding violations sampled, 86 percent of violations (i.e., vehicle speed greater than 5 mi/h above the posted speed limit) were issued correctly. A large proportion (83.0 percent) of speeding violations occurred between 60 and 85 mi/h (136.8 km/h). According to the non-violation speeding sample, the OBMS correctly identified that the CMV was traveling below the posted speed limit 96 percent of the time. An important caveat of these findings is that the status of vehicle speeding did not target posted speed limits as the threshold for speeding, but rather 5 mi/h above posted speed limits. Furthermore, due care was exercised by the research team to conclude the OBMS had missed a speeding violation only if the difference in vehicle speed was greater than 6 mi/h above the posted speed limit. The same care was exercised for concluding an OBMS violation false alarm had occurred if the difference in vehicle speed was less than 4 mi/h above the posted speed limit. These findings confirm anecdotal and questionnaire feedback from the drivers.

According to the seatbelt violations sampled, 100 percent were issued correctly. Non-violations were sampled across a wide range of speeds to determine if drivers might choose to sit on the seatbelt while it was latched. According to the non-violation seatbelt sample, the OBMS correctly identified that the seatbelt was latched 100 percent of the time. Based on the assessment of seatbelt use, drivers did not try to avoid wearing the seatbelt while leaving it latched.

The number of recorded aggressive driving violations was very low. There were too few violations (30) during the intervention phase to establish a robust accuracy test sample for violation and non-violation periods. There was only one record of a hard-bump violation. There were 18 recorded hard-turn violations, with an average vehicle speed of 18.8 mi/h (30.3 km/h) and a 0.43 g-force. There were 11 recorded hard-brake violations, with an average vehicle speed of 28.6 mi/h (46.0 km/h) and a 0.53 g-force.

The research team assessed the intervention phase audible feedback activity to determine if the system delivered alerts to drivers prior to and after violations were recorded (thus informing the drivers of the need to adjust driving performance). Assessment of clear audio for 531 speeding violations demonstrated feedback success for 505 violations (95 percent). Assessment of clear audio for 340 seatbelt violations demonstrated feedback success for 297 violations (87 percent).

To measure fuel efficiency, researchers selected fuel flow as the vehicle measure with the least inherent error. Other measures (e.g., average and instantaneous fuel efficiency) combine other sensors—which carry additional error—to estimate the rate of work being accomplished. The fuel flow rates were averaged per drive file and compared between separate groups of drivers who were active in different phases—baseline versus intervention—during the same month. The fuel flow rate for the intervention group was significantly greater than the flow rate for the baseline group. The effect of the OBMS on fuel efficiency was inconclusive.

4.2 POTENTIAL SAFETY BENEFITS

The research team determined the potential safety benefits of the OBMS by assessing drivers' rate of involvement in SCEs during the baseline and intervention periods. Researchers considered additional effects of the OBMS on driving behavior by analyzing the number of OBMS speeding and seatbelt violations averaged across all vehicles between the baseline and intervention phases and tracing the trends of speeding and seatbelt violations across the intervention phase.

The instrumented DASs collected approximately 1.2 million miles worth of naturalistic driving data for 17 drivers. That collection resulted in 311 valid SCEs across the baseline and intervention phases. After curb strike and driver not-at-fault SCEs were removed, 208 SCEs remained across the baseline and intervention phases. For at-fault SCEs excluding curb strikes, the baseline mean rate of SCEs per 10,000 VMT was 1.4 compared to the intervention mean rate of 1.1. The reduction in rate from the baseline phase to the intervention phase was not significantly lower across all drivers; however, 11 of the 17 drivers did have a reduced rate of at-fault SCEs from baseline to intervention.

To further compare the effect of the OBMS on safety performance, the research team analyzed the rates of OBMS speeding violations per 1,000 miles occurring during baseline, intervention, and across intervention. The speeding violation rates were averaged across all 17 drivers. The most striking effect of the speeding violations was the 37 percent reduction in the first 2-week period of intervention. That rate continued to drop until the fourth 2-week period. Overall, the reduction in the rate of speeding violations was statistically significant from baseline to intervention. However, at the fifth 2-week period, the rate continued to increase until it peaked again at the ninth 2-week period, which was not significantly better than the baseline phase. It is apparent that the drivers responded to the in-cab feedback during the early stages of the intervention period, but that effect seemed to disappear over time.

An additional safety performance metric was the rate of seatbelt violations per 1,000 miles averaged across all drivers from baseline to intervention and across intervention. Similar to the early intervention change in the rate of speeding violations, the rate of seatbelt violations per 1,000 miles averaged across all 17 drivers reduced by 56 percent from baseline to the first 2-week intervention period. Unlike the speeding violations, all 17 drivers reduced their seatbelt violations from baseline to overall intervention. Similarly, the rate of seatbelt violations averaged across all drivers remained significantly below the baseline rate at each 2-week intervention period.

4.3 USER ACCEPTANCE

An investigation of drivers' opinions of the OBMS performance during normal driving revealed the following:

- The seven participants surveyed in the study agreed with the safety benefits analyses performed by the research team. A majority of drivers had experience with in-vehicle technologies (e.g., lane departure warning systems, GPS, etc.). All of the drivers had experience with electronic logging systems due to the fleet's instrumentation. Drivers' ratings of OBMS usefulness, effectiveness, and level of annoyance did not change significantly from the pre-test to post-test period. General positive comments included the following: "reminds you to wear your seatbelt," "made me a better driver," and "kept you from speeding a lot." General negative comments included the following: "would not have correct speed limits" and "seatbelt warning set at too low of a speed, should be at least 20 mi/h, verbal warning while moving in yard, 5 mi/h = too slow."
- The fleet manager and the dispatcher indicated that drivers did not initially like having the current OBMS (or previous OBMSs) in their trucks, but over time they tended to recognize that an OBMS can help them do their job better. While the fleet manager and the dispatcher thought the OBMS improved drivers' seatbelt usage and reduced speeding, they did have some concerns about the system's inability to distinguish between CMV and light vehicle split highway speeds. Finally, the fleet manager suggested that it may be difficult to justify the OBMS economically because the system currently requires the time of a manager to coach drivers.

4.4 STUDY LIMITATIONS

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

- The measurement of the system's accuracy for speed is affected by the repeated number of violations that a driver may get on the same road if he or she repeatedly exceeds and satisfies the system's posted speed limit status (which may not always match the roadside posted speed limit). The OBMS technology provides a method for the fleet managers to report road speed updates on the portal, but that requires coordination between the driver and the fleet manager, as well as entry of error notes in the portal by the fleet manager.
- The OBMS vendor communicated during training and repeated refresher meetings that significant lasting improvements come with strong engagement between fleet managers and their drivers on a regular and consistent basis. Monthly meetings between the vendor and the fleet, as witnessed by the research team, suggested that interactions discussing drivers' weekly performance (as measured by the OBMS) between fleet managers and their drivers were limited. The frequency of attendance by any or all of the fleet team was observed but not recorded.
- While the limited data captured on aggressive driving can be viewed as good performance by the drivers, challenges created by fleet policy and instrumentation (e.g., calibrating sensors with a tractor and loaded trailer connected) can lead to limited application of the aggressive driving features and measures of the same.
- Measures of fuel efficiency can be influenced by many factors, such as differences between vehicles (e.g., model years, driver-vehicle route, and vehicle sensors).

5. RECOMMENDATIONS

The evaluation of this specific OBMS provides some valuable guidance for the CMV industry.

- **Suggestions for Improving the OBMS Technology.** Based on the results of this field test, there appear to be opportunities for some improvement:
  - Providing in-cab feedback for violations, such as for speeding and seatbelt use, is a useful tool for drivers to learn to improve their driving performance—as long as the referenced information or posted speed limits are very accurate.
  - Regular audits of posted speed limits should be performed as road and highway posted speed limits change over time. The differentiation between light vehicle and heavy vehicle (truck) speed limits should be available for CMV applications.
- **Suggestions for Fleet Coaching.** Active engagement between the fleet managers and drivers should be regular and consistent to obtain the maximum benefit from the OBMS.
- **Industry Application.** The application of OBMSs may provide a useful resource for fleets that desire to improve safe-driving performance:
  - The accuracy of the seatbelt sub-system and the lasting improvement of seatbelt use observed during the study suggest that the after-market application of seatbelt instrumentation at the buckle alone is a beneficial step toward improving seatbelt usage.
  - Fleets that implement OBMSs should carefully consider the configuration based on their application and drivers' needs (e.g., the absolute minimum vehicle speed at which seatbelt violations are activated).
  - Fleets that implement OBMSs should be aware of occasional inconsistencies in measures, such as speed, when mentoring their drivers.
- **Better Understanding of Fleet Manager-Driver Interaction.** Future evaluations of OBMSs should include tracking of fleet manager-driver interactions so that the exact frequency is known to enable a comparative analysis of the effects of interactions between separate fleet entities or between drivers (within a specific fleet).

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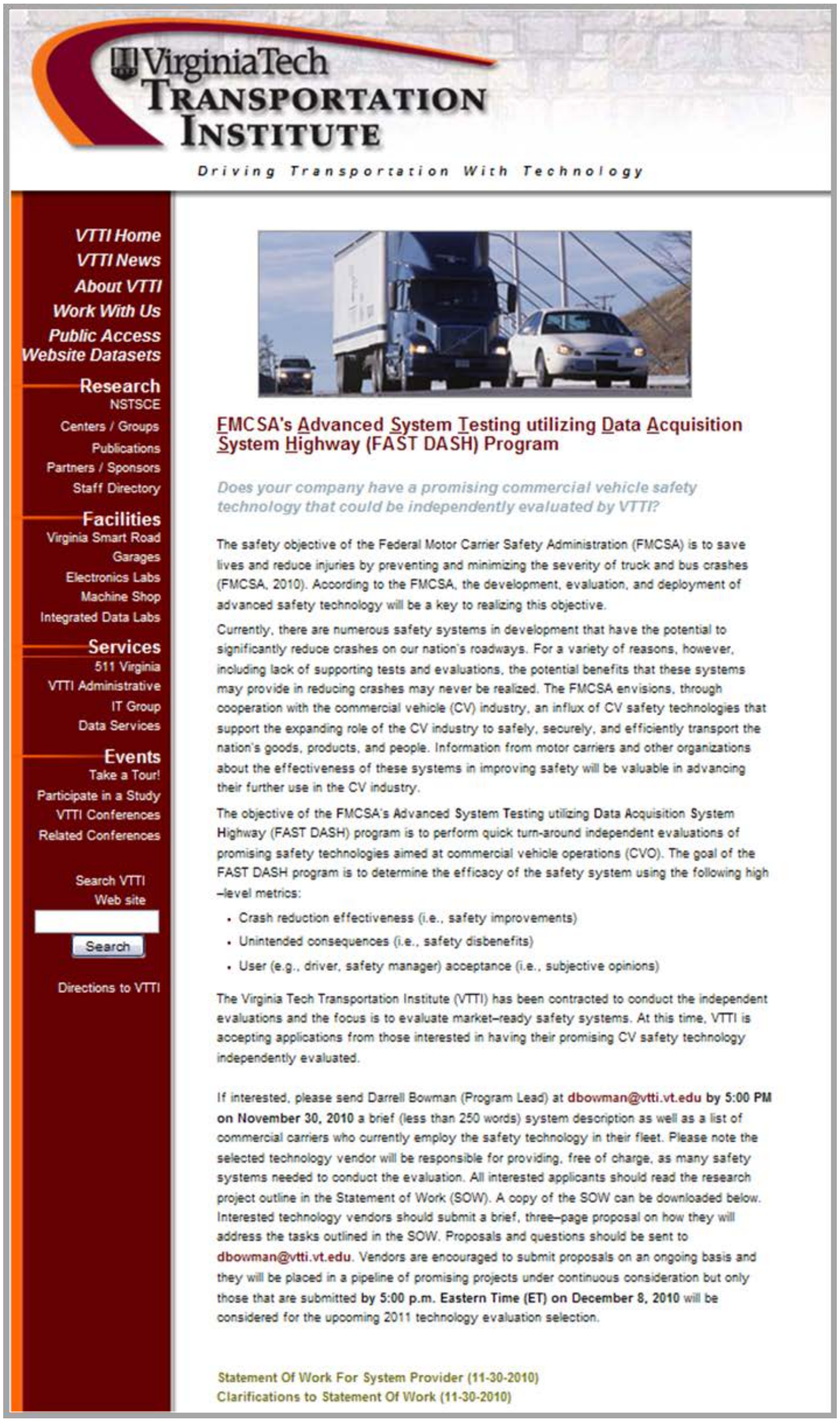
APPENDIX A: VENDOR SOLICITATION WEB SITE



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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: WAYSMART FEATURES AND SPECIFICATIONS

inthinc™
→waySmart 850

Fleet Management Solutions

inthinc waySmart™ creates dramatic changes in the driving behavior of your fleet while also providing your business with tremendous control and quick ROI. Powered by inthinc innovations including in-cab mentoring, GPS, Speed-by-Street™ and an SAE J-211 compliant crash data recorder, waySmart is the most comprehensive heavy-duty fleet safety system on the market.

In-cab Verbal Coaching — Send automated in-cab verbal alerts in real-time when drivers are speeding or driving aggressively

Seat Belt Use Alerts — Ensure drivers are wearing a seat belt while driving by sending alerts to drivers and managers alike

Speed-by-Street™ — Send automated verbal alerts to drivers when they exceed the speed limit on any given road segment

Driver/Fleet Scoring — Assign driver/fleet scorecards to identify safe drivers and those in need of additional training

Crash & Roll-Over Detection — Receive instant notification via phone, text or e-mail when a vehicle has been in an accident

Fuel Use and MPG Tracking — Monitor miles per gallon (mpg) for each fleet vehicle on a daily basis for up to 12 months

Idle Monitoring and Alerts — Monitor idling behaviors of drivers and identify those who are not in compliance with corporate policy

Work AloneTimer — Allow drivers to set up timers warning management if they do not return to the vehicle in a given time frame

Driver Vehicle Inspection Reports (DVIR) — Create fully customizable vehicle inspection checklists for operators to complete using the waySmart touch screen

Electronic Hours-of-Service Logs — Avoid hassles associated with erroneous paper logs while eliminating timely administrative overhead

Road Hazard Awareness — Allow drivers to communicate with each other regarding hazardous areas including debris, construction and severe weather conditions

Automated Exception Alerts — Receive instant notifications via text, e-mail or phone call when a driver has been in a crash or committed a serious violation

smartZones™ — Draw geo-fences around regions or sites to enforce customizable attributes including speed limits and hazard warnings

GPS Tracking — Ensure routes are efficient and vehicles are being used appropriately to maximize fleet efficiency

Live Fleet Visibility — Monitor driver location and route details in real-time, including distance and time traveled

Automated IFTA Tax Reporting — Capture when vehicles cross state lines and calculate appropriate tax amount for gallons consumed versus gallons purchased

Vehicle Inspection Alerts — Send timed checklist alerts to remind drivers of pre/post-trip instructions and inspection requirements

Injury Severity Modeling — Receive detailed reports of every crash via black box technology including vehicle speed, GPS location, direction of vehicle, RPMs and more—recorded 20 seconds before and 10 seconds after a crash

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Hardware Specifications:

Power:	
Input Power:	8 to 36VDC, surge protection to 80V
Internal Reserve Power:	Non-battery: up to 60-seconds if external loss of power
Processor Core:	
Processor:	Freescale i.MX534 ARM Cortex-A8 CPU, 800MHz
Memory:	Volitile: 512MB / Non-volatile: 2GB
Peripherals:	
Time:	Battery backed up real-time clock
External Upgradable Storage:	MicroSD: SDHC and SDXC compatible
Digital I/O:	USB 2.0 device port for debug / Audio output / 1-wire for driver login (iButton connector type)
	6 GPIO's (seat belt sense, ignition sense 12V or 24V support, cable for RF Kill switch)
	4 RS-232 serial ports, 1MB/s, full duplex (optional: Iridium satellite combination modem and antenna module, I/O expansion)
External Power Connector:	Supported
Vehicle BUS Interface:	Native format: CAN (two channel) J1939 & J1708
	Vehicle BUS Dongle: SAE-J1850 (VPW & PWM), ISO9141-2, ISO14230-4 (KWP2000), ISO15765 (CAN)
Driver Behavior Module:	
Sensor:	Tri-axial accelerometer, programmable from 4G± to 8G± dynamic range
Crash Detection:	Supported
Environmental:	
Temperature:	Operating: -40°C to +85°C / Storage: -45°C to +85°C
Humidity:	5% to 95% relative humidity
Dust & Moisture:	IP65
Corrosive Resistance:	NEMA 4X equivalent, ASTM D543-06
Case Impact Resistance:	IK05 (eq. 200g mass from 35cm) or ASTM D2794-93 (direct impact), ASTM D256-10, SAE J1455 (1m drop on to concrete)
Vibration Resistance:	ISTA over-the-road truck profile
Abrasion Resistance:	To be tested per ISO 9352:95
Electrostatic Shock:	ANSI/IEEE C62.38
Electromagnetic:	APTA SS-E-010-98
Regulatory:	
Electromagnetic Emissions:	FCC Class B / CE / C-Tick
Safety:	UL / CE mark
Environmental:	RoHS and WEEE

inthinc

GSA Schedule

APPENDIX C: WAYSMART INTERFACE GUIDE

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APPENDIX D: PRE-STUDY QUESTIONNAIRE

Pre-Study Questionnaire

Instructions

Please answer the following questions by marking the answer that best matches your response. Please choose **only one** of the following:

In the past 12 months while driving, how often did you…

1. Run red lights?
   - O Never
   - O Rarely
   - O Sometimes
   - O Often
2. Change lanes suddenly to get ahead of traffic?
   - O Never
   - O Rarely
   - O Sometimes
   - O Often
3. Go through a stop sign without stopping?
   - O Never
   - O Rarely
   - O Sometimes
   - O Often
4. Speed for the thrill of it?
   - O Never
   - O Rarely
   - O Sometimes
   - O Often
5. Not yield the right of way?
   - O Never
   - O Rarely
   - O Sometimes
   - O Often

6. Make illegal turns?

   O Never

   O Rarely

   O Sometimes

   O Often

7. Follow a car very closely or “tailgate”?

   O Never

   O Rarely

   O Sometimes

   O Often

8. Take more risks because you were in a hurry?

   O Never

   O Rarely

   O Sometimes

   O Often

9. Drive at your normal speed during bad driving conditions, like road construction, rain, ice or snow?

   O Never

   O Rarely

   O Sometimes

   O Often

10. Pass other cars on the right side on the shoulder of the road?

   O Never

   O Rarely

   O Sometimes

   O Often

11. Accelerate when a traffic light turned yellow?

   O Never

   O Rarely

   O Sometimes

   O Often

12. Cut off, honk or yell at other drivers who drive too slowly or cut you off?

- O Never
- O Rarely
- O Sometimes
- O Often

13. Do other things while driving, like use cell phone, eat or drink, read things, or smoke cigarettes?

- O Never
- O Rarely
- O Sometimes
- O Often

14. Take your eyes off the road to adjust the CD player or pick something up from the floor?

- O Never
- O Rarely
- O Sometimes
- O Often

15. Not check your mirrors when passing another car or merging onto the highway?

- O Never
- O Rarely
- O Sometimes
- O Often

16. Driver 10-20 mph over the limit?

- O Never
- O Rarely
- O Sometimes
- O Often

17. Driver more than 20 mph over the limit?

- O Never
- O Rarely
- O Sometimes
- O Often

18. Not yield to pedestrians?

O Never

O Rarely

O Sometimes

O Often

19. Drive without wearing a safety belt?

O Never

O Rarely

O Sometimes

O Often

20. Turn without signaling?

O Never

O Rarely

O Sometimes

O Often

21. Pass where visibility was obscured?

O Never

O Rarely

O Sometimes

O Often

22. Not make a full stop at stop sign?

O Never

O Rarely

O Sometimes

O Often

BACKGROUND

The waySmart® system is a fleet management system that improves driver performance, fuel efficiency, and truck-to-fleet communication. The driver is audibly alerted to aggressive driving behaviors, seatbelt use, and speeding. This system also allows driver to monitor their miles per gallon on a daily basis, and also provides improved communications between drivers and dispatch regarding hazardous areas encountered during their driving. The purpose of this study is to evaluate waySmart® in a real-world environment.

1) **How much do you like the idea of having *waySmart* 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 *waySmart* would be…**

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

	1	2	3	4	5	6	7	
irritating	1	2	3	4	5	6	7	likeable
worthless	1	2	3	4	5	6	7	assisting
undesirable	1	2	3	4	5	6	7	desirable
sleep-inducing	1	2	3	4	5	6	7	raising alertness

3) What are two things you think you will like about *waySmart*?

1. ______________________________

2. ______________________________

4) What are two things you think you will dislike about *waySmart*?

1. ______________________________

2. ______________________________

APPENDIX E: POST-STUDY QUESTIONNAIRE

Post-Study Questionnaire

Instructions

Please answer the following questions by placing an X on each line below that best matches your response.

Placing an X on lines between numbers is also allowed (for example, placing an X halfway between 4 and 5 resulting in a selection of 4.5 is allowed).

1) How much do you like the idea of having *waySmart* on your truck?

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 *waySmart* is… (Please place an X on each line below that best matches your response)

useless 1 2 3 4 5 6 7 useful

unpleasant 1 2 3 4 5 6 7 pleasant

bad 1 2 3 4 5 6 7 good

annoying 1 2 3 4 5 6 7 nice

ineffective 1 2 3 4 5 6 7 effective

irritating	1	2	3	4	5	6	7	likeable
worthless	1	2	3	4	5	6	7	assisting
undesirable	1	2	3	4	5	6	7	desirable

3) **How does your driving performance with *waySmart* compare to your driving performance without *waySmart*?**

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 *waySmart* in my truck"**

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: "*waySmart has made me a safer driver.*"**

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: “*waySmart* encourages regular seatbelt use.”**

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

7) **How much do you agree with the statement: “*waySmart* effectively alerts me about speeding.”**

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

8) **How much do you agree with the statement: “*waySmart* has improved my fuel efficiency.”**

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

9) **How much do you agree with the statement: “*waySmart* is easy to use.”**

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

10) **How uncomfortable is the glare from the display when you are driving at night and looking forward down the road?**

11) How uncomfortable is the glare from the display when you are driving at night and looking directly at the light?

1	2	3	4	5	6	7
Extremely Uncomfort-able	Very Uncomfort-able	Uncomfort-able	Neutral	Comfortable	Very Comfort-able	Extremely Comfort-able

12) Were you able to become familiar with how the system worked in the first month?
(Circle your answer below)

YES (if yes, skip to 14) **NO** (if no, answer 13 and 14)

13) How long did it take you to become familiar with how the system worked?

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

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

1.

2.

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

1.

2.

Additional Comments

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

1. ____

2. ____

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APPENDIX F: FLEET MANAGER INTERVIEW QUESTIONS

Fleet Manager Interview

Safety Benefits

1. Do you think drivers using a *waySmart* system would change their on-road driving?
    1. If yes: why/in what ways?
    2. If no: why?
2. What types of routes does your company primarily operate? (***IF company runs different route types***) Would a *waySmart* system help local/regional, line, and long haul drivers differently?
    1. If so, why
    2. If not, why?
3. If the *waySmart* 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

4. 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 *waySmart* technology change driver training within your company.
        1. If so, how?
5. What do you think drivers' initial reaction to *waySmart* was?
6. 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

7. 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?
8. What maintenance concerns do you have regarding this system?

Economic Issues

9. If possible, could you please estimate the costs associated with crashes incurred each year by:
    1. Your terminal?
    2. Your company?
10. How much would you be willing to pay for this system in your fleet per truck?

11. What factors 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?
12. In your opinion, would the additional cost of *waySmart* be economically justified?
13. Would federal or insurance incentives influence the decision on whether or not your company would adopt a *waySmart* system?
14. Would liability issues affect your decision?
15. What is the biggest issue or issues you see in using this technology?
16. In general, do you feel the *waySmart* system would be useful in your company?

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

Company Information

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

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REFERENCES

1. Federal Motor Carrier Safety Administration. (2006). *Report to congress on the large truck crash causation study*. Washington, DC.
2. *Ibid.*
3. Federal Motor Carrier Safety Administration. (2014). *Commercial motor vehicle safety belt facts*. Retrieved from: http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Safety_Belt%20Factsheet_508.pdf.
4. Federal Motor Carrier Safety Administration. (2015). *Large truck and bus crash facts 2013*. Retrieved from: https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Large-Truck-and-Bus-Crash-Facts-2013_0.pdf.
5. Hickman, J. S., & Geller, E. S. (2005). Self-management to increase safe driving among short-haul truck drivers. *Journal of Organizational Behavior Management*, *23*(4), 1-20.
6. Hickman, J. S., & Hanowski, R. J. (2011). Use of a video monitoring approach to reduce at-risk driving behaviors in commercial vehicle operations. *Transportation research part F: Traffic psychology and behavior*, *14*(3), 189-198.
7. Federal Motor Carrier Safety Administration. (2014). Our mission. Retrieved on June 7, 2015, from http://www.fmcsa.dot.gov/mission.
8. Federal Motor Carrier Safety Administration. (2006). *Report to congress on the large truck crash causation study*. Washington, DC.
9. *Ibid.*
10. Federal Motor Carrier Safety Administration. (2014). *Commercial motor vehicle safety belt facts*. Retrieved from: http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Safety_Belt%20Factsheet_508.pdf.
11. Federal Motor Carrier Safety Administration. (2015). *Large truck and bus crash facts 2013*. Retrieved from http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Large-Truck-Bus-Crash-Facts-2012.pdf.
12. Federal Motor Carrier Safety Administration. (2014). *Commercial motor vehicle safety belt facts*. Retrieved from: http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Safety_Belt%20Factsheet_508.pdf.
13. *Ibid.*

14. Schaudt, W. A., Bowman, D. S., Hanowski, R. J., Olson, R. L., Marinik, A., Soccolich, S., Joslin, S., Toole, L., & Rice, J. C. (2014). *Federal Motor Carrier Safety Administration's Advanced System Testing Utilizing a Data Acquisition System on the Highways (FAST DASH): Safety Technology Evaluation Project #1 Blindspot Warning: Final Report* (FMCSA-RRT-13-008). Washington, DC: Federal Motor Carrier Safety Administration. Retrieved from http://ntl.bts.gov/lib/51000/51400/51416/FAST-DASH-Concurrence-Package.pdf.

15. *Ibid.*

16. *Ibid.*

17. *Ibid.*