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Independent Evaluation of Heavy-Truck Safety Applications Based on Vehicle-to-Vehicle and Vehicle-to-Infrastructure Communications Used in the Safety Pilot Model Deployment

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16. Abstract

This report presents the methodology and results of the independent evaluation of heavy trucks (HTs) in the Safety Pilot Model Deployment (SPMD); part of the United States Department of Transportation's Intelligent Transportation Systems research program. In 2012 the SPMD deployed approximately 2,800 vehicles equipped with designated short-range-communication-based vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technology in a real-world driving environment. The goals of the independent evaluation were to characterize capability, assess unintended consequences, and gauge driver acceptance of the V2V and V2I safety applications. The evaluation is based on naturalistic driving by 33 participants who drove HTs equipped with integrated and retrofit safety devices (RSDs). The V2V and V2I devices in the 3 integrated trucks and 16 trucks equipped with RSDs contained a suite of safety applications that issued alerts to participants in potential crash scenarios. The results of the analysis suggest that V2V safety applications work in real-world environment and issue useful alerts in driving conflicts, but improvements in their accuracy are needed. Results from the SPMD will help shape future research direction.

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Foreword

The Volpe National Transportation Systems Center (Volpe), in support of the National Highway Traffic Safety Administration, has conducted an independent evaluation of crash warning applications based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication using data collected from the Safety Pilot Model Deployment (SPMD) field test. As a Federal organization, Volpe is independent in that they are not involved in the development of technology and do not financially benefit from commercialization of future products based on the technology. This evaluation was a research project under a broad intra-agency agreement (IAA) between NHTSA and Volpe to assess the safety benefits of V2V crash avoidance systems for heavy trucks. This report documents the approach and results of the independent evaluation. Another IAA between Volpe and NHTSA is in place to conduct an independent evaluation of light vehicle crash warning applications using data from the SPMD field test, and an IAA between Volpe and the Intelligent Transportation Systems Joint Program Office is in place to conduct an independent evaluation of transit bus crash warning applications using data from the SPMD field test. In addition to this independent evaluation report, there are companion reports on the independent evaluation results of light vehicle and transit bus crash warning applications.

Table of Contents

Figures

Tables

List of Acronyms

ANOVA	analysis of variance
ASD	aftermarket safety device
BSW	blind spot warning
CAN	controller area network
CSW	curve speed warning
CV	connected vehicle
DAS	data acquisition system
DNPW	do not pass warning
DSRC	dedicated short range communication
DVI	driver-vehicle interface
EEBL	emergency electronic brake light
FCW	forward collision warning
HT	heavy truck
HV	host vehicle
IAA	intra agency agreement
IMA	intersection movement assist
IQR	interquartile range
LCW	lane change warning
LTAP	left turn across path
LTIP	left turn into path
LVD	lead vehicle decelerating
LVM	lead vehicle moving
LVS	lead vehicle stopped
SPMD	Safety Pilot Model Deployment
PET	post encroachment time
RSD	retrofit safety device
RSE	roadside equipment
RV	remote vehicle
SD	standard deviation
TTC	time-to-collision
TTI	target time to intersection
UMTRI	University of Michigan Transportation Research Institute
VAD	vehicle awareness device
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VMT	vehicle miles traveled

Executive Summary

This report presents the methods and results of the independent evaluation of the heavy truck vehicle-to-vehicle and vehicle-to-infrastructure safety applications used in the 2012 – 2013 Safety Pilot Model Deployment. The SPMD program was part of the United States Department of Transportation's Intelligent Transportation Systems research program and focused on the development and evaluation of crash avoidance systems. These crash avoidance systems were based on V2V and V2I technologies that communicate through dedicated short range communication. The vision of the SPMD program was to test V2V communication based safety applications in real-world driving scenarios to determine their effectiveness at reducing crashes, and to verify that the technology does not cause negative unintended consequences.

The U.S. DOT's Volpe National Transportation Systems Center (Volpe) conducted the independent evaluation for the SPMD safety applications. As a Federal organization, Volpe is independent in that it is not involved in the development of technology, and does not financially benefit from commercialization of future products based on the technology.

The goals of the SPMD evaluation are to:

- Characterize system performance and capability of V2V- and V2I-based safety applications (i.e., determine the accuracy of the warnings issued by the safety applications).
- Assess the unintended consequences from driving with V2V safety applications (i.e., determine if there are any situations where the safety applications negatively impacted driver safety).
- Determine driver acceptance of the V2V- and V2I-based safety applications (i.e., gauge driver perception and approval of the safety applications).

Methodology

This evaluation is based on data collected during the SPMD—a one-year naturalistic field test of 2,800 vehicles equipped with DSRC devices and V2V and V2I safety applications—conducted in a real-world environment on public roadways in Ann Arbor, MI. The University of Michigan Transportation Research Institute is the Test Conductor.

During the SPMD, eight participants employed by Sysco Foods, LLC, drove eight Sysco trucks equipped with DSRC retrofit safety devices developed by Battelle (hereafter referred to as RSD1s) for a period of 17 months. It should be noted here that the Sysco trucks were driven in the SPMD area for an additional 6 months to collect additional data. Sixteen participants employed by Con-way, Inc.,[1] drove eight Con-way trucks equipped with DSRC RSDs (hereafter referred to as RSD2s) developed by Southwest Research Institute for a period of 11 months. Two participants employed by 4H Transportation Inc. drove two trucks equipped with fully integrated DSRC V2V and V2I systems for a period of 5 months. Two participants employed by Rightaway Delivery drove one integrated truck for a period of 3 months. Five participants from UMTRI drove the above three integrated trucks for a period of 5 months. The integrated trucks and 16 RSDs contained a suite of safety applications that issued alerts to participants in potential crash scenarios. The safety applications on the integrated trucks were directly integrated to the truck's controller area network bus, thus providing the ability to draw on a wide range of data. The RSDs were not connected to the CAN bus. They draw data only from the environment (e.g., GPS, safety messages from other vehicles) to support applications. RSDs can emit the basic safety message to warn equipped vehicles of the vehicles presence as well as warn drivers of potential conflicts. The two integrated trucks

[1] [Editor's Note: In 2013 Con-way, headquartered in Ann Arbor, was the country's third largest transportation and logistics company. On September 9, 2015, Con-way announced it was being acquired by XPO Lositics, Inc., headquartered in Greenwich, Connecticut. As this report went to press, it was not known how the acquisition would affect the Con-way brand name.]

provided to 4H did not issue any alerts due to fleet routes outside the SPMD area. In addition, there were a small number of alerts issued by the integrated truck provided to Rightaway. This was due to Rightaway ending its involvement in the study due to the loss of its freight contract which covered the cities near the SPMD area. As a result, the three integrated trucks were driven in the SPMD area by the UMTRI drivers to increase the exposure of these vehicles to other similarly equipped vehicles in the SPMD area. The trucks were assigned arbitrary five-digit serial numbers such as "integrated truck #15501" for tracking and recordkeeping purposes.

The independent evaluation focuses on five HT safety applications:

V2V:

- *Forward-Collision Warning*: warns drivers of slower moving, slowing or stopped vehicles in their path of travel.
- *Intersection Movement Assist*: warns drivers of vehicles approaching from a lateral direction at an intersection.
- *Blind-Spot and Lane-Change Warning*: alerts drivers to the presence of vehicles in their blind spot and warns them if turn signal is activated for lane change (RSD1s equipped with BSW only and integrated trucks equipped with both BSW/LCW).
- *Emergency Electronic Brake Light*: alerts drivers to heavy braking ahead in the traffic queue.

V2I:

- *Curve Speed Warning*: warns drivers when approaching a curve at a speed higher than indicated by the roadside equipment.

System Capability

The evaluation looked at the ability of these five safety applications to appropriately issue warnings in the SPMD environment. Volpe, as the independent evaluator, categorized crash-imminent alerts based on the remote vehicle location and driving scenario, classified alerts as potentially valid or invalid (i.e., false alerts), and searched for false-negative (missed) alerts to identify scenarios where basic alert conditions were satisfied but an alert was not issued. The evaluation of system capability did not attempt to explain the root cause in case of observed abnormal performance. It should be noted that due to video synchronization issues with two of the integrated trucks, data from the third truck (truck #15501) was used in the evaluation. In addition, a small amount of FCW data (video with limited numerical data) was collected from the RSD2s.

Key findings are listed below:

FCW Findings

- The percentage values of FCW alerts issued for in-path RVs were 12 percent and 43 percent for RSD1s and RSD2s respectively, and 32 percent for the integrated truck #15501. The remaining alerts were issued for RVs that were not in-path and therefore not a threat (false alerts). It should be noted here that the FCW alerts issued by the RSD2s were evaluated by examining video data only since there was limited numerical data available. This precluded information on range, range rate, speed, etc. from being examined.
- The in-path alert percentage of FCW alerts issued for stopped RVs was lower than for moving RVs for both RSD1s and integrated truck #15501. Due to the small number of alerts issued by the RSD2s, this data was not included in the analysis.
- The majority of in-path alerts were issued during lead vehicle decelerating (LVD) scenarios for both RSD1s and integrated truck #15501. Limited numerical data collected from the RSD2s precluded this information from being obtained.

- Alerts issued for RVs between 30 and 60 m away had the highest in-path percentages for both the RSD1s and integrated truck #15501. Due to limited numerical data, RV range data was not available from the RSD2s.
- Regarding alert performance by RV device type, similar trends were observed between the RSD1s and the integrated truck #15501. There was a large disparity (78% compared to 9%) in percentages of RSD1 in-path alerts triggered by RSD1 equipped trucks compared to in-path alerts triggered by after market safety devices and vehicle awareness devices combined. There was also a large difference (94% compared to 25%) in percentages of integrated truck in-path alerts triggered by remote integrated trucks compared to in-path alerts triggered by ASDs and VADs combined. Limited numerical data collected from the RSD2s precluded this information from being obtained.
- There was one observed instance of a potential missed (false negative) FCW alert event in the RSD1 dataset.

IMA Findings

- The percentage values of IMA alerts that occurred at intersections were 37 percent and 63 percent for the RSD1s and integrated truck #15501 respectively. The remaining 63 percent and 37 percent of the alerts issued by the RSD1s and integrated truck #15501 respectively were false alerts.
- The majority of the false alerts (50% of all IMA alerts) issued by the RSD1s occurred at an overpass. These false alerts represent opportunities for software refinement to account for elevation in the GPS data. The percentage of false alerts issued at an overpass by the integrated truck was small (7%). This could be attributed to the UMTRI drivers driving in areas where there were no overpasses. It could also be that the integrated truck system accounts for elevation in the GPS data.
- One potential missed (false negative) IMA stopped (the host vehicle is proceeding into an intersection from a stop) alert event was identified in the RSD1 dataset.
- There were no observed instances of potential missed (false negative) IMA moving (the host vehicle is approaching an intersection at speed) alert events in the SPMD.

BSW/LCW Findings

- Eighty-eight percent of BSW alerts issued by the RSD1s were for RVs in the adjacent lane. None of the events involved a steering response from the driver. It should be noted here that the RSD1s were equipped with BSW only (cautionary alert with no audio).
- Seventy-one percent of BSW/LCW alerts issued by the integrated truck #15501 were for vehicles in the adjacent lane. None of the events involved a steering response from the driver.
- There was one observed potential missed (false negative) LCW alert event in the integrated truck #15501 dataset.

EEBL Findings

- Eleven of the alerts (73%) issued by the RSD1s were for in-path and adjacent lane RVs. Two of the eleven events involved an obstructing lead vehicle.
- All five alerts issued by the integrated truck were for in-path RVs. One of the five events involved an obstructing lead vehicle.

CSW Findings

- All the CSW alerts were issued by the RSD1s. The majority of the alerts were issued at the entry points to equipped curves located on Plymouth Road (71%) and Bonisteel Boulevard (65%). The percentage values of alerts issued in the equipped curves located on Plymouth Road and Bonisteel Boulevard were 12 percent and 35 percent respectively. The percentage of CSW alerts issued at curve entry and in the equipped curve on both Plymouth Road and Bonisteel Boulevard combined is 91 percent.

- All CSW alerts were issued at or above the threshold speeds. None of the CSW alert events involved the driver braking when the alert was issued.
- Two events, extracted from the RSD1 data, were identified as potential missed (false negative) CSW alerts.

Unintended Consequences

Volpe did not observe any instances where the V2V safety applications had a negative impact on driver safety based on the observation of drivers' reactions to 37 crash-imminent alerts (i.e., 5 FCW and 32 IMA alerts) issued in potential hazard scenarios by the V2V safety applications.

Driver Acceptance

Volpe looked at driver acceptance of the technology (including whether or not participants perceive a safety benefit from using the technology) based on survey data collected from each participant after they completed the SPMD. One participant filled out a survey for the integrated truck, eight participants filled out surveys for the RSD1s, and sixteen participants filled out surveys for the RSD2s.

Key findings are as follows:

- Only one participant who used the integrated truck filled out a survey, preventing any statistical generalization to the wider population. This participant felt that the safety benefits of the warning system were nullified by the distraction caused by looking down at the screen to identify the type of alert being issued since this was not possible based on the audio tones alone. This participant was neutral with regard to wanting to have the system and was not willing to pay any money for it.
- Sample sizes for the RSD1s and RSD2s were larger, but still small reducing generalizability to the wider population.
- The system was given mostly neutral ratings with regard to overall satisfaction, desirability, understandability, rated effectiveness at alerting the driver to a potential collision, and perceived safety benefits.
- The CSW (RSD1) tended to receive higher ratings than the other safety applications.
- Distraction and overreliance were not seen as big concerns by most participants.
- More than half of participants were not willing to have the system if it enabled the government, a business entity, or a third party to learn about their driving behavior and patterns. This was true even for "appropriate personnel" to prevent criminal behavior such as hacking.
- The more alerts a participant received per vehicle miles traveled (VMT), the higher they rated warning effectiveness and perceived safety benefits, the more they agreed that the system was no more distracting than a car radio, and the more willing they would be to have the system if it required periodic trips to the shop for updates.
- Especially with regard to survey questions asking participants to rate their agreement with a statement, the large number of neutral responses may indicate that participants were unsure how they felt. This may possibly be due to a lack of experience with the alerts given how few there were overall (and due to alerts only occurring with the subset of interactions that occurred with other equipped vehicles). This would explain why responses tended to be more favorable with

increasing rates of alerts per VMT, at least with regard to perceived effectiveness and safety benefits.

Conclusions

The evaluation of HT V2V and V2I safety applications was limited to data collected from the RSD1s and one integrated truck.

In regard to unintended consequences, Volpe did not observe any instances where the V2V safety applications had a negative impact on driver safety.

More than half of the participants were not willing to have the system if it enabled the government, a business entity, or a third party to learn about their driving behavior and patterns. The more alerts a participant received per vehicle miles traveled, the higher they rated warning effectiveness and perceived safety benefits.

Overall, the SPMD demonstrated that V2V and V2I technology can be deployed in a real-world driving environment. The experimental design was successful in creating naturalistic interactions between the DSRC-equipped vehicles. As a result, the safety applications issued warnings in the safety-critical driving scenarios that they were designed to address. It should be noted here that there were no crashes in this study.

The SPMD was also crucial in revealing areas for improving performance of the emerging DSRC technology and the prototype safety applications, which could not have been identified in controlled testing environments.

1 Introduction

This report presents the analytical approach and results of the independent evaluation of the heavy-truck safety applications deployed in the 2012 and 2013 SPMD field test. The SPMD program was part of the United States Department of Transportation's Intelligent Transportation Systems research program and focuses on the development and evaluation of crash warning systems. These crash warning systems were based on V2V and V2I technologies that communicate through dedicated short range communication at 5.9 GHz. The U.S. DOT goal for this program was to accelerate the introduction and commercialization of the DSRC-based crash warning systems. The program is intended to establish vehicle communications for the surface transportation system that will support applications to enhance safety and mobility. The vision of the SPMD is to test V2V and V2I safety applications in real-world driving scenarios to determine their effectiveness at reducing crashes, and to verify that the technology does not cause unintended consequences.

Volpe conducted the independent evaluation for the SPMD. As a Federal organization, Volpe is independent in that it is not involved in the development of technology, and does not financially benefit from commercialization of future products based on the technology. The evaluation of the SPMD is based on the data collected during the SPMD—a naturalistic real-world V2V and V2I field test of 2,800 V2V-equipped light vehicles, HTs, and transit buses—conducted in Ann Arbor. The University of Michigan Transportation Research Institute was the test conductor for the SPMD.

This report evaluates V2V and V2I safety applications on HTs with the following two types of DSRC devices installed:

- Integrated trucks developed by the Battelle Connected Commercial Vehicle Team; and
- Retrofit safety devices, one set developed by Battelle (hereafter referred to as RSD1s) and another set developed by Cambridge Systematics/Southwest Research Institute team (hereafter referred to as RSD2s).

Volpe also evaluated the SPMD light vehicle and transit bus safety applications and will present these results in separate reports [1] [2].

1.1 Safety Applications

The evaluation focused on the following V2V and V2I safety applications:

- *Forward-Collision Warning:* warns drivers of slower moving, slowing, or stopped vehicles in their path of travel.
- *Intersection Movement Assist:* warns drivers of vehicles approaching from a lateral direction at an intersection.
- *Blind-Spot and Lane-Change Warning:* alerts drivers to the presence of vehicles approaching or in their blind spot and warns them if turn signal is activated for lane change.
- *Emergency Electronic Brake-Light:* warns drivers of heavy braking ahead in the traffic queue.
- *Curve Speed Warning)*[2]*:* warns drivers when approaching a curve at a speed higher than indicated by the roadside equipment.

Table 1 lists safety applications by platform. Two different levels of warning were implemented in the SPMD Safety applications; cautionary warnings provide information that may be helpful to the driver's situational awareness (for example, letting drivers know there is a vehicle in their blind spot, even though they are not showing intent to change lanes), and crash-imminent warnings are designed to make drivers aware of an imminent threat (for example, letting drivers know there is a vehicle in their blind spot when

[2] CSW is a V2I application.

they have shown intent to change lanes). In Table 1, a “C” indicates that a given manufacturer’s implementation of the safety application had a cautionary (advisory) component; “I” indicates that driver interface had an imminent component, and “C/I” indicates that the driver interface had both an advisory and an imminent component. Generally, when both warning types are implemented, the cautionary warning would be issued first, and if the scenario is escalated to a higher threat, it would be followed by the imminent warning. For the integrated truck and RSD1s, both cautionary and imminent alerts had a visual and auditory component with the exception of BSW, which displays a visual warning only with no audio. The RSD2s were equipped with imminent warnings only with both visual and auditory components.

This evaluation focused on the crash-imminent component of the safety applications because crash-imminent alerts have a direct safety impact in potential crash scenarios, while cautionary warnings provide situational awareness. In addition, the evaluation also included the analysis of the cautionary component (no audio) of the BSW/LCW application found in the RSD1.

Table 1. Safety Applications by Platform

Platform	Safety Applications				
	FCW	IMA	BSW/LCW	EEBL	CSW
Integrated Safety Systems	C/I	C/I	C/I	C/I	C/I
RSD1s	C/I	C/I	C	C/I	C/I
RSD2s	I			I	I

C= Cautionary alert I = Imminent alert C/I = Cautionary and imminent alert

The majority of the data was collected from the FCW and IMA safety applications found on the integrated truck and RSD1s. There was limited FCW data collected from the RSD2s and no data collected for EEBL and CSW.

1.2 Independent Evaluation Goals

The goals of the independent evaluation of the V2V and V2I safety applications installed in heavy trucks in the SPMD are to:

1. *Characterize system performance and capability of the safety applications.* This goal addresses the ability of the V2V and V2I safety applications to appropriately issue warnings in the SPMD environment.
2. *Determine if there are unintended consequences from driving with V2V safety applications.* The second goal determines if there are any observed instances of negative behavior adaptations associated with the safety applications.
3. *Determine driver acceptance of the V2V and V2I safety applications*. This goal evaluates how participants perceive the technology with respect to usability, safety benefits, understandability, desirability, and security and privacy issues.

The RSD1s were evaluated for system capability, unintended consequences and driver acceptance. The RSD2s were evaluated for system capability and driver acceptance only. In regard to the integrated truck, the evaluation focused on system capability. Due to technical issues (see Section 2.5.4) encountered with the integrated trucks and limited data collected by the RSD2s, the main focus of this evaluation was on the RSD1s.

2 Model Deployment

This evaluation is primarily based on data collected during the SPMD, which deployed about 2,800 vehicles equipped with DSRC devices with V2V and V2I safety applications on public roadways in Ann Arbor. The goal of the SPMD was to collect performance data on DSRC technology and on DSRC-based safety applications operating in real-world conditions. The one-year SPMD launched on August 21, 2012, and collected data from a variety of different types of vehicles (passenger cars, HTs, and transit buses) and DSRC devices. It should be noted here that the data collection period was extended for six months for the RSD1s to increase the amount of data collected.

2.1 Experimental Design

Twenty-eight of the 33 participants who drove HTs were commercial drivers. The remaining 5 participants were UMTRI drivers. Eight participants employed by Sysco Foods, LLC, drove eight trucks equipped with RSD1s for a period of 17 months. Sixteen participants employed by Con-way drove eight trucks equipped with RSD2s for a period of 11 months. Two participants employed by 4H Transportation, Inc., drove two integrated trucks for 5 months. Two participants employed by Rightaway Delivery drove one integrated truck for a period of 3 months. It should be noted here that Rightaway ended its involvement in the study due to the loss of its freight contract that covered the cities near the SPMD area. In addition, 5 UMTRI drivers drove the three integrated trucks for a period of 5 months. The participants who drove the trucks equipped with RSDs and completed the questionnaire at the end of their driving period were all male with a majority of them between the ages of 35 to 55 years old. There was one female driver from Rightaway who completed the questionnaire and was 45 to 54 years old.

It should be noted here that due to a small number of alerts issued to the Rightaway drivers and no alerts issued to the 4H drivers (due to the integrated trucks being driven outside the SPMD area), the UMTRI drivers were recruited to drive the three integrated trucks in the SPMD area under non-naturalistic conditions[3] to increase the exposure of these vehicles to other similarly equipped vehicles in the SPMD area.

It should be noted here that all of the RSD1s were equipped with a data acquisition system and half of the RSD2s were equipped with a DAS.

In addition to the integrated and RSD-equipped HTs, the SPMD also deployed approximately 2,390 vehicle awareness devices in about 2,220 passenger vehicles, 75 buses, and 100 medium/HTs. VADs transmit the basic safety message so that they can be detected by other V2V equipped vehicles, but they do not receive messages or provide safety application alerts to the drivers. VADs are "visible" by other device types, but are significantly less expensive and easier to install than integrated devices or aftermarket safety devices, allowing more DSRC devices to be deployed in total. In addition, there were also 64 integrated light vehicles, 3 integrated buses, and 300 light vehicles equipped with ASDs.

2.2 Recruitment Strategy

UMTRI recruited the study participants. The recruitment strategy was designed to maximize equipped vehicle traffic around the SPMD area. The goal was to create same-direction and cross traffic V2V interactions (scenarios where two V2V-equipped vehicles are in close proximity). UMTRI targeted trucking companies that it was familiar with and that conducted local deliveries in the SPMD area. Sysco is a major food supplier to UMTRI and was happy to participate. Con-way has done multiple field operational tests with UMTRI, which also had a long-term relationship with the UMTRI's vice president of safety. Rightaway is a local delivery company. One of its drivers made a delivery to UMTRI, learned

[3] UMTRI drivers were assigned pre-prescribed routes which were not typical routes driven by the professional truck drivers.

about the project, and mentioned it to the owner of the company. Rightaway contacted UMTRI and expressed a desire to participate. The 4H company is a small over-the-road trucking company near Ann Arbor. UMTRI held a conversation with the owner during a delivery to UMTRI. The owner agreed to participate. Participants were paid $200 each when they completed the questionnaire at the end of their driving periods. It should be noted here that if drivers did not receive any alerts, they were not required to fill out the surveys. Therefore, the drivers from 4H did not submit questionnaires following the completion of their driving periods.

Recruits were selected to drive vehicles equipped with VADs and ASDs [1] so they can interact with the equipped HTs.

2.3 Heavy Truck Participant Demographics

This subsection provides an overview of the demographics for the HT participants in the SPMD. Table 2 lists the driver demographics for the Sysco, Con-way, and Rightaway drivers.

Table 2. Demographics for HT Drivers

Truck Fleet	Total No. of Drivers	Sex	Age Category				
			18-24	25-34	35-44	45-54	55-64
Con-way	16	M		1	3	7	5
Sysco	8	M		2	4	1	1
Rightaway	1	F				1	

Driver acceptance analysis was conducted using data collected from the Sysco (RSD1s) and Con-way (RSD2s) trucks. Since only one survey was received from Rightaway, no quantitative analysis was conducted using this data.

2.4 Summary of Exposure to Application Alerts

HT participants received 1,089 crash-imminent alerts during the SPMD.

2.4.1 Number of Alerts by Safety Application

Figure 1 shows the breakdown of crash-imminent alerts by safety application. The majority of the alerts were issued for FCW and IMA. There were a small number of FCW alerts issued by the RSD2s. In addition, due to video synchronization issues with two of the three integrated trucks (devices 15101 and 15901 (see section 2.5.4)), data from only one integrated truck #15501 was used in the evaluation.

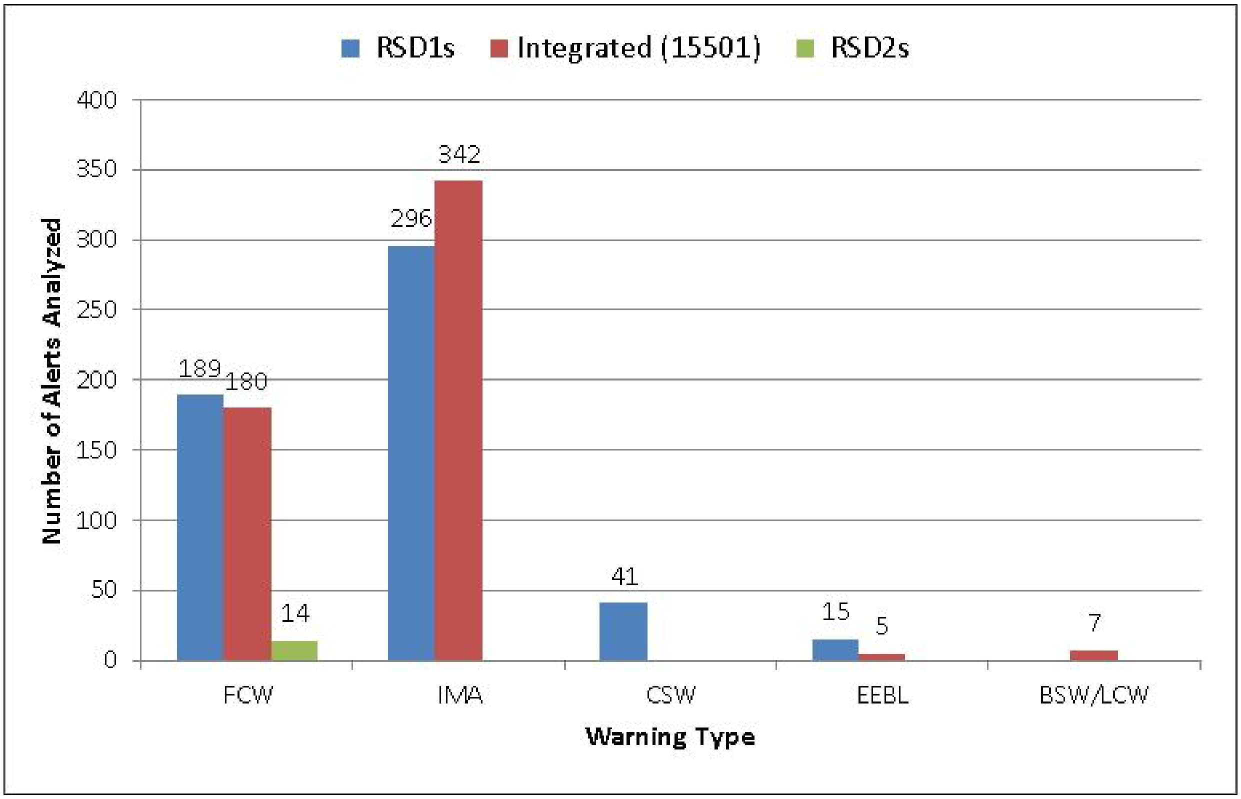

Figure 1. RSD and Integrated Truck #15501 Alerts by Safety Application

2.4.2 Number of Alerts by Retrofit Safety Device

Figure 2 shows the total number of crash-imminent alerts for each RSD. The top three devices with the largest number of FCW and IMA alerts were truck #13101, truck #13107, and truck #13109.

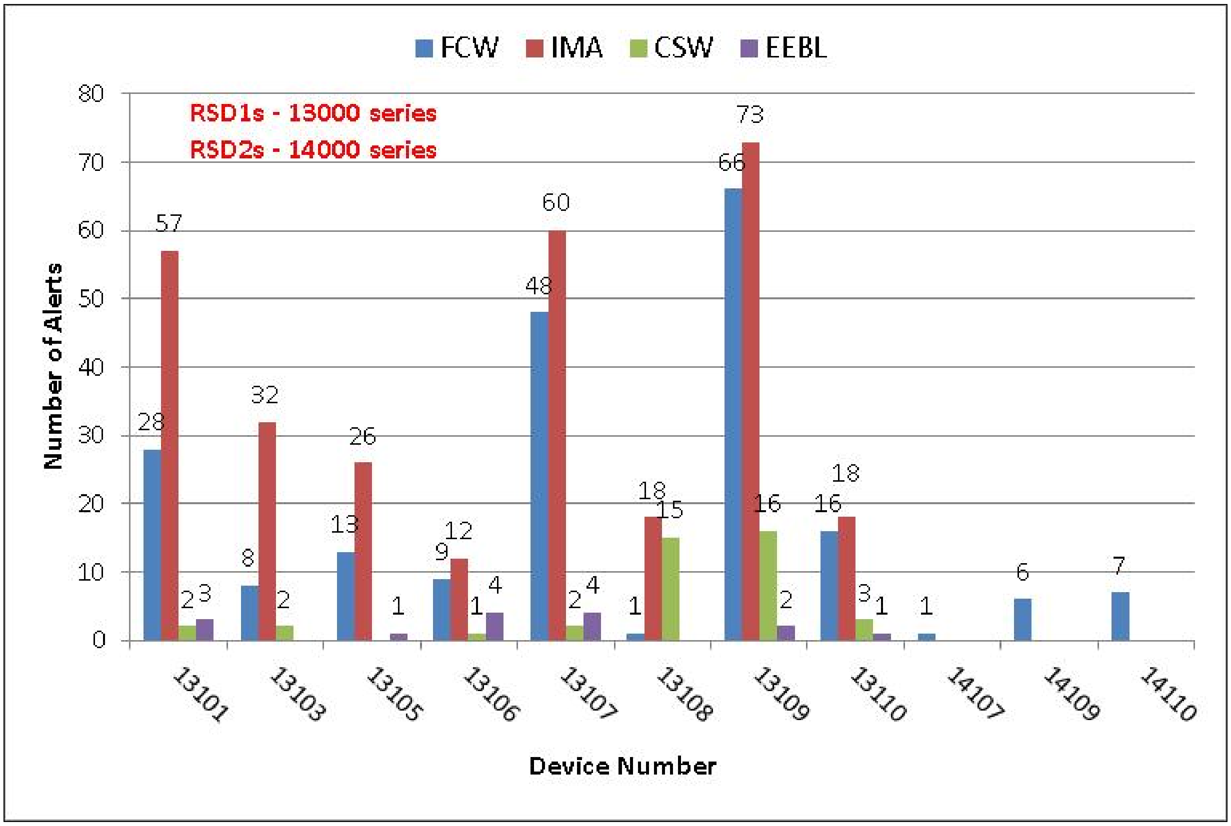

Figure 2. Total Number of Crash-Imminent Safety Application Alerts by RSD

2.4.3 Alert Rates

Figure 3 shows the number of FCW and IMA alerts for each RSD1 and integrated truck #15501, normalized by mileage. Due to the small number of FCW alerts issued by the RSD2s, these values are not included here. Normalizing the alerts by miles driven shows the same trend exhibited in Figure 2 (i.e., trucks #13101, #13107, and #13109 issued the most FCW and IMA alerts). The integrated truck issued the most alerts per 1000 miles driven. It should be noted that the total miles driven for each truck ranged from 20,000 to 30,000 miles. The trucks with the highest number of alerts were driven an average of 21,000 miles. The higher alert rates issued by the integrated truck #15501 could be attributed to the non-naturalistic routes driven by the UMTRI drivers. As stated previously, the UMTRI drivers were recruited to drive the three integrated trucks in the SPMD area under non-naturalistic conditions to increase the exposure of these vehicles to other similarly equipped vehicles in the SPMD area. These drivers were assigned pre-prescribed routes which were not typical routes driven by the professional truck drivers.

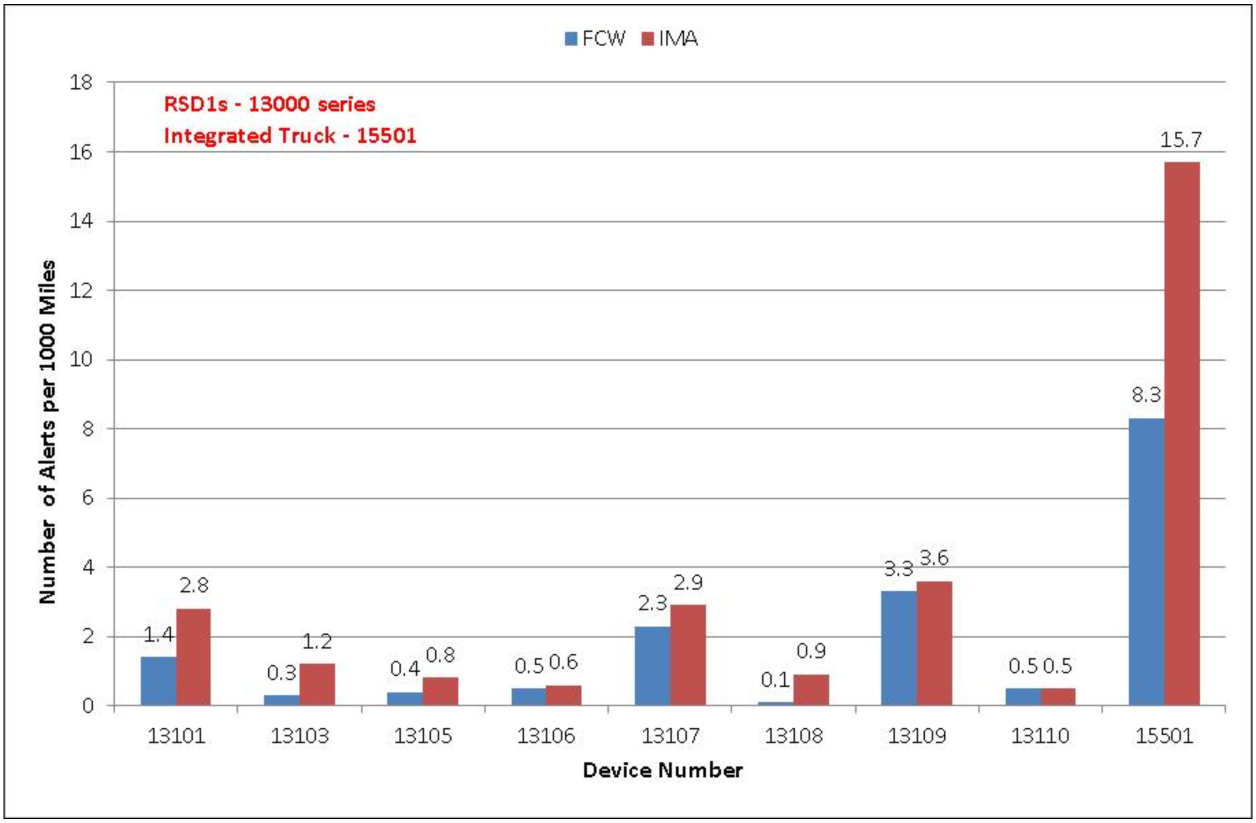

Figure 3. Number of Crash-Imminent Alerts per 1000 Miles Driven for Each RSD1 and Integrated Truck #15501

2.5 Data Sources

Volpe used data from the SPMD to evaluate the HT safety applications in the SPMD. There are two primary types of data, objective and subjective.

The majority of the objective data was collected from the integrated trucks and the Sysco trucks equipped with the RSD1s. Of the 33 participants who drove the HTs, only 25 submitted surveys (i.e., subjective data). Prior to their participation, drivers were told what data would be collected and how it would be used. Drivers who agreed to participate consented to the collection of their driving data during the field test.

2.5.1 Objective Data

The objective data consists of numerical and video data. Objective data is collected by the DAS connected to the vehicle's CAN bus, DSRC device, and other external sensors. Data is collected continuously when the ignition of the equipped vehicle is turned on.

The numerical data are collected and stored at a rate of 10 Hz, and consist of the following categories.

- *In-vehicle data*: data collected from the vehicle's CAN about vehicle inputs (e.g., steering/throttle/controls) and vehicle dynamics (e.g., speed/acceleration)
- *V2V data*: information about other equipped vehicles within DSRC range (e.g., speed/heading/location)

- *External sensors*: location of surrounding objects and the host vehicle's position within the lane (e.g., lane tracking/forward radar). These sensors are part of the DAS and not for the operation of safety applications
- *Application data*: information about when and why types of alerts are being issued to the participants

Four video views are captured and synchronized with the numerical data. The video data allow Volpe to view the driver face and the vehicle surroundings. Figure 4 shows the video views for the HT data (both integrated trucks and RSD1s). These include (clockwise from top left):

- Forward,
- Driver's face and cabin,
- Right side, snd
- Left side.

There were three video views available from the RSD2s. These included forward view, over-the-shoulder view, and side view of driver. There was limited numerical data collected from the RSD2s.

Table 3 lists for each database the number of records (i.e., lines of data; for most data elements one line of data is collected every 1/10th of a second) and number of hours of driving represented by the data. Due to inconsistent data collection rates in the RSD2, this information cannot be determined.

Table 3. Model Deployment Objective Data Sources

	Integrated Trucks	RSD1s	RSD2s
Records (10 Hz)	139 million	332 million	n/a[4]
Hours	4,000	9,000	n/a

[4] n/a denotes data is not available due to inconsistent data collection rates from the RSD2s

Figure 4. HT Equipped With Battelle RSD Video Data

2.5.2 Subjective Data

All 24 participants who drove the trucks equipped with the RSDs completed a questionnaire at the end of their participation in the SPMD. One of nine participants who drove the integrated trucks completed the questionnaire. The questionnaires consisted of open-ended questions, multiple choice questions, and questions answered using a 7-point Likert scale. The Likert scale questions asked participants to rate the degree in which they either agreed or disagreed with a series of statements, as shown in Figure 5. After a preliminary section containing questions about the overall suite of safety features, the survey then broke down into separate sections for each alert type. Participants were only given those sections of the survey corresponding to the features on the vehicle they drove.

a. It was clear *why* the system was warning you when it warned you

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Figure 5. Likert Scale Question Format Used on Driver Acceptance Questionnaire

The V2V and V2I safety applications were addressed as a whole, in addition to being broken down by individual safety applications. Appendix A contains the complete questionnaire.

2.5.3 Mapping Data Sources to Goals

Table 4 lists the data sources used to address each of the three Evaluation goals.

The system capability and unintended consequences analyses used objective data, while the driver acceptance analysis used a combination of objective and subjective data. However, the limited number of objective data collected from the RSD2s precluded the data from being used in driver acceptance analysis. The assessment of unintended consequences was addressed only with data from the RSD1s. System capability was addressed with integrated truck, RSD1, and RSD2 data. Driver acceptance was addressed with RSD1 and RSD2 data.

Table 4. Breakdown of Evaluation Data Sources and Goals

Evaluation Goals	Integrated Trucks		RSD1s		RSD2s	
	Objective	Subjective	Objective	Subjective	Objective	Subjective
System Capability	X		X		X	
Unintended Consequences			X			
Driver Acceptance			X	X		X

2.5.4 Technical Issues and Constraints

There were video synchronization issues for data collected from two (trucks #15101 and #15901) of the three integrated trucks. In addition, the data was non-naturalistic since the trucks were driven by UMTRI drivers during the last 5 months of the SPMD field test. Therefore, data from these two trucks was not used in the evaluation. However, the data collected from the third integrated truck (truck #15501) was of sufficient sample size to perform system capability analysis.

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3 System Capability

The system capability analysis characterizes the ability of the V2V and V2I applications to perform as expected in the SPMD environment. While the analysis focuses on performance of the safety applications, the results inherently reflect the SPMD environment as a whole. This environment includes the security implemented to provide trusted and secure V2V communications and the variety of prototype devices and antenna configurations. The performance of the safety applications is impacted by the safety application software and the quality of the data sent and received from infrastructure and other V2V-equipped vehicles.

The system capability analysis conducted by Volpe addresses the observed performance of the safety applications during the SPMD. This analysis is based on visual inspection of video data, backed by relevant numerical data. It does not attempt to explain the root cause in case of observed abnormal performance.

The V2V applications examined include FCW, IMA, BSW/LCW, and EEBL. The V2I application examined was CSW.

3.1 Technical Approach

This subsection describes the technical approach used to characterize the capability of the V2V and V2I safety applications in the SPMD.

Crash-imminent alerts were categorized based on the remote vehicle location and driving scenario when application alerts were issued. Alerts were classified as potentially valid or invalid based on the type of driving scenario each individual application was designed to address. In addition to examining alerts, Volpe looked at missed alerts (false negatives). This included scenarios where a valid warning trigger was present and basic alert conditions were satisfied, but an alert was not issued. Table 5 lists alert classifications based on RV location.

Table 5. Alert Classification by RV Location

	RV Location		
	In-Position	**Out-Of-Position**	**No RV**
Alert	Valid Alert	False Alert	False Alert
No Alert	Missed Alert	Valid Rejection	Valid Rejection

3.1.1 Alert Accuracy

Volpe conducted alert classifications using a video analysis tool developed by Volpe. This tool synchronizes and displays video from ten seconds before and five seconds after each application alert, in addition to the corresponding numerical data from the database and the physical location of the host and remote vehicles (on a map). It allows analysts to validate the position of the RV and the dynamics of both vehicles at the time of the alert. Analysts used the data displayed by the tool to code a variety of attributes and classify the alerts using the input boxes shown on the right side of Figure 6. The coded variables include: information about the location of the vehicles at the time of the alert, the driving maneuvers of both vehicles, participant behavior, participant's response to the alert, and environmental conditions. Appendix B lists all coded variables and definitions. It should be noted that the video analysis tool was used to conduct alert classifications for the data collected from the RSD1s and integrated truck #15501. The data collected from the RSD2s was not compatible with the data analysis tool. Therefore, the analysis of the RSD2 data consisted of analyzing video data only. Limited numerical data collected from the RSD2s precluded any numerical analysis.

Figure 6. Video Analysis Tool

Table 6 shows the primary attribute used to assess the performance for each of the five safety applications, and the value that indicates that the alert is a valid alert.

Table 6. Safety Application Classification Variables and Values

Safety Application	Classification Variable	Possible Values	Valid Alert Value
FCW	Forward Target Location	In-path, One lane over, Two lanes over, Other	In-path
IMA	Intersection Target Location	Approaching intersection, In intersection, Overpass, Cloverleaf, Curved Road, Rotary, Other	Approaching intersection, In intersection
BSW/LCW	Lane Change Target Location	Adjacent lane, In-Lane, Two lanes over, Other	Adjacent lane
EEBL	Forward Target Location	In-path, One lane over, Two lanes over, Other	In-path, One lane over

Safety Application	Classification Variable	Possible Values	Valid Alert Value
CSW	Host Vehicle Position	Curve entry, In-curve, Curve exit, Other	Curve entry, In-curve

Additional variables used in the alert classification breakdowns include:

- Target vehicle motion (moving/stopped)
- Target device type (Integrated vehicle, ASD, VAD, HT, etc.)
- Road geometry

3.1.2 Missed Alerts

Missed alerts are relevant to application performance because if a safety application fails to issue an alert in a driving scenario that it was designed to address, the application cannot provide a safety benefit to the driver.

Volpe approached the analysis of missed alerts in an exploratory manner, with the intent to find scenarios that resembled the vehicle dynamics of the alert scenarios that did not trigger alerts. This analysis was not intended to be exhaustive, but rather to gain anecdotal insight into the types of scenarios in which missed alerts occurred. Volpe does not have proprietary warning logic to determine when alerts should be issued or suppressed, and therefore cannot confirm or deny the presence of a missed alert.

The following subsections cover missed alert analysis for FCW, IMA, BSW/LCW, and CSW.

3.1.2.1 FCW

Volpe detected potential missed FCW alerts using an algorithm that identified scenarios where the HT had a hard braking response to a V2V-equipped RV, but did not receive an FCW alert.

Potential missed FCW alert scenarios fit the following criteria.

- Range to V2V-equipped RV is < 70 m
- Equipped RV is traveling in the same direction as the HV (RV heading angle within ±5degrees of the HV heading)
- Range from V2V data within ±5 m of the range from forward in-path mobile-eye data (to target scenarios where the HV is following a RV that may be the V2V-equipped vehicle within range)
- HV instantaneous deceleration > 0.15g while time to collision (TTC) < 15 s
- Speed of primary RV detected by radar is > 0 m/s
- No FCW or EEBL alerts triggered during the event

Volpe analyzed the video from each scenario to validate that the lead RV was V2V-equipped, then compared the vehicle dynamics of the HV and the RV to the vehicle dynamics observed in the FCW alert scenarios.

3.1.2.2 IMA

IMA Stopped

For IMA events where the HV stopped at the intersection and waited to proceed, potential missed alert events included specific scenarios. One example is where the driver creeps forward into the intersection, while an equipped RV was also approaching the intersection from a lateral direction.

Potential missed IMA-stopped scenarios fit the following criteria.

- HV enters intersection
- HV speed < 4.4 m/s (HV is stopped at intersection prior to entering)
- RV approaches the same intersection from a lateral direction (heading differential between HV and RV between 80 and 100 degrees)
- RV speed >11 m/s (RV threshold speed for IMA moving alert activation)
- RV moves within 20 m of HV
- RV is not braking
- No IMA alert (inform or warn) during event

Volpe analyzed video from each scenario to confirm the presence of a V2V-equipped RV and its distance away from the intersection.

IMA Moving

For IMA events where the HV is approaching an intersection, potential missed alert events included specific scenarios. For example, the driver executed a hard braking maneuver, while an equipped RV was approaching from a lateral direction.

Potential missed IMA moving scenarios fit the following criteria.

- Maximum HV instantaneous deceleration > 0.4 g
- V2V-equipped RV approaches the same intersection from a lateral direction (heading differential between HV and RV between 80 and 100 degrees)
- RV speed >11 m/s

Volpe analyzed video from each scenario to confirm the presence of a V2V-equipped RV and its distance away from the intersection.

3.1.2.3 BSW/LCW

Potential missed LCW alerts included specific scenarios. For example, the driver executed a lane change when the V2V equipped vehicle was in close proximity to the HV.

Potential missed LCW scenarios fit the following criteria.

- HV Speed > 25 mph and RV Speed > 11 mph
- Turn signal activated
- HV is on a road with minimum of two same-direction travel lanes
- HV is not within 100 m from (approaching) intersection (to ignore scenarios where the participant is showing intent to turn at intersection)
- HV is not on an exit ramp (to ignore scenarios where the participant is showing intent to exit freeway)
- Range to V2V-equipped RV is < 20 m at onset of turn signal
- RV heading is within 5 degrees of HV heading
- No LCW alert is triggered during the event

Volpe analyzed video from each scenario to confirm the presence of a V2V-equipped RV and its distance away from the HV.

3.1.2.4 CSW

Potential missed CSW alert events fall into one of the scenarios below, which are based on the GPS of each curve entry (coming from both directions) and the speed of the vehicle.

Potential missed CSW scenarios fit the following criteria.

- HV is approaching, entering, or traversing
  - The Bonisteel Boulevard-equipped curve at a speed over 30 mph
  - The Plymouth Road-equipped curve at a speed over 40 mph
- No CSW alert is triggered during the event

Volpe analyzed video to determine the location of the HV within the curve when the speed was above the CSW threshold.

3.2 Results

The following subsection contains bar charts and scatter plots displaying the application performance results, broken down by device type and safety application. Results are also presented for the proportion of alerts in each category that were analyzed. Labels on top of the bars represent the total number of events in each category.

3.2.1 FCW Results

3.2.1.1 This subsection presents results of application performance and missed alerts analysis for FCW crash imminent warnings issued by the integrated truck (truck #15501) and RSD1s and RSD2s. The FCW safety application warns drivers of slower-moving, slowing, or stopped vehicles in their path of travel. FCW Alert Performance

FCW performance results are broken down by the relative location of the RV at alert onset:

- *In-path:* refers to RVs that are in the same lane of travel and in the intended path of the HV. Alerts were considered in-path if any part of the RV was in the HV's lane at the onset of the alert.
- *Out-of-path*: refers to RVs that are either in the adjacent lane, left turn lane, or two lanes over and therefore do not pose a threat to the HV. Alerts in this category are false alerts.
- *Other:* refers to alerts triggered for RVs that are not in a potential rear-end threat position (e.g., behind the HV, or moving away from the HV). Alerts in this category are false alerts.

3.2.1.1.1 FCW Alert Performance by RV Position

Figure 7 shows the RV position of the 383 FCW alerts analyzed from integrated truck #15501 (180 alerts) and RSDs (203 alerts).

- The percentage values of FCW alerts issued for in-path RVs were 12 percent and 43 percent for RSD1s and RSD2s respectively, and 32 percent for the integrated truck #15501.
- The percentage values of the FCW alerts issued for out-of-path RVs by the RSD1s and integrated truck #15501 were 53 percent and 39 percent respectively.
- The percentage values of FCW alerts issued for other RVs were 35 percent and 57 percent for RSD1s and RSD2s respectively, and 29 percent for the integrated truck #15501.

It should be noted that upon receiving the alert, the driver took the appropriate action. There were no crashes in this study.

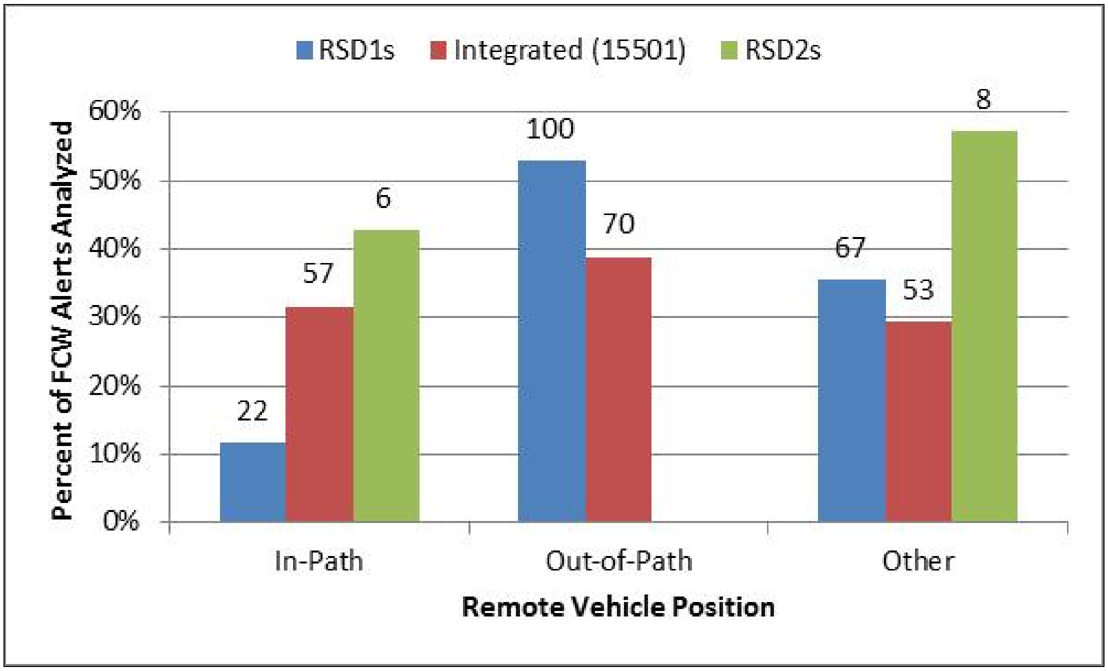


Figure 7. FCW Alerts by RV Position

3.2.1.1.2 Detailed Breakdown of FCW False Alerts

Figure 8 shows a detailed breakdown of the FCW false alert categories. The first three subcategories shown on the horizontal axis in Figure 8 are a breakdown of the "out-of-path" category, and the last four are a breakdown of the "Other" category.

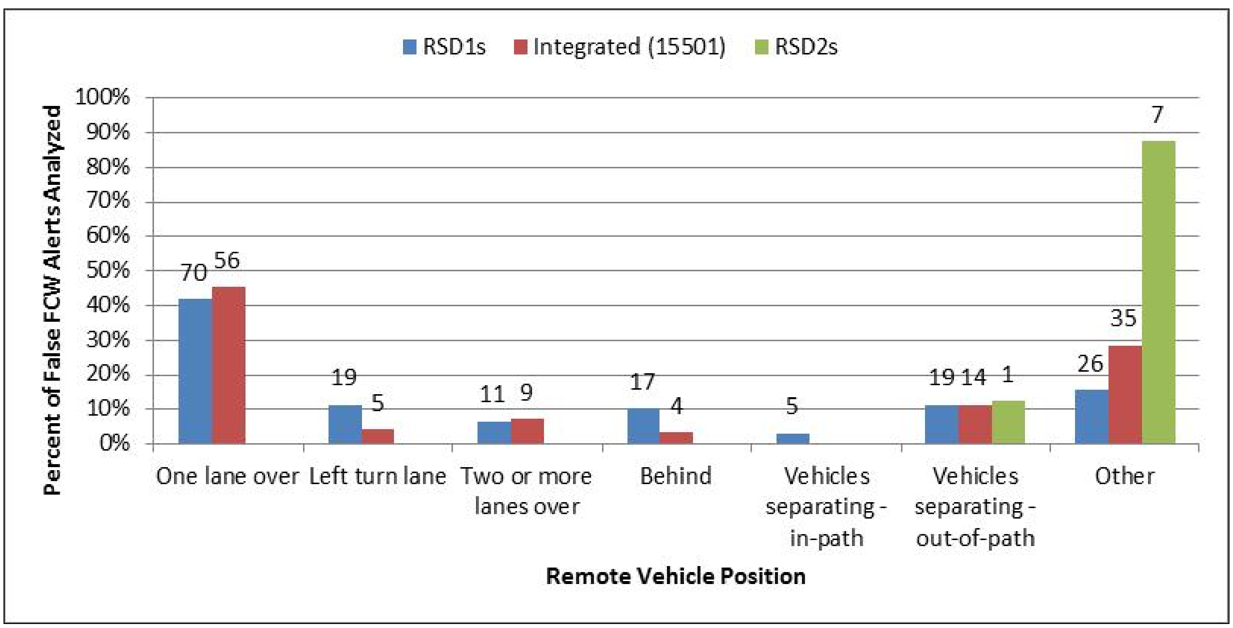


Figure 8. Detailed Breakdown of False FCW Alerts by RV Position

Definitions for these categories are listed below.

- *One lane over:* RV is in the travel lane adjacent to the HV.
- *Left turn lane:* RV is one lane over, in the dedicated left turn lane preparing to go left at an intersection.
- *Two or more lanes over:* RV is in a same direction travel lane two or more lanes over from the HV.
- *Behind:* RV is behind, or traveling adjacent to the HV.
- *Vehicles separating, in-path:* RV is in the path of the HV, but moving away from the HV (traveling faster).
- *Vehicles separating, out-of-path:* RV is in the travel lane adjacent to the HV, and moving away from the HV (traveling faster).
- *Other:* A RV could not be identified (including alert events with no forward video), RV was off the roadway or not positioned appropriately for an FCW alert (e.g., in an adjacent parking lot, on a lateral roadway, or traveling the opposite direction).

The results in Figure 8 do not show any major differences in the percent of false alerts issued for the out-of-path RVs between RSD1s and integrated truck #15501. The majority of the false alerts issued by RSD2s were for RVs in other positions.

3.2.1.1.3 FCW Alert Performance by RV Motion

To assess the impact of the RV dynamics on alert performance, the FCW performance data were broken down by stopped RVs and moving RVs. The RV motion was determined within three seconds of alert onset. The results for RSD1s and integrated truck #15501 are shown in Figure 9 and Figure 10 respectively. It should be noted here that 21 FCW events extracted from RSD1s contained unknown RV motion and therefore, were not included in the analysis. In addition, 27 FCW events extracted from the integrated truck #15501 contained unknown RV motion and were not included in the analysis. In addition, due to the small number of FCW alerts issued by the RSD2s, this data was not included in the analysis.

- The in-path percentage for stopped RVs was 8 percent for RSD1s (Figure 9).
- The in-path percentage for moving RVs was 17 percent (Figure 9).
- The in-path percentage for stopped RVs was 26 percent for the integrated truck (Figure 10).
- The in-path percentage for moving RVs was 41 percent (Figure 10).

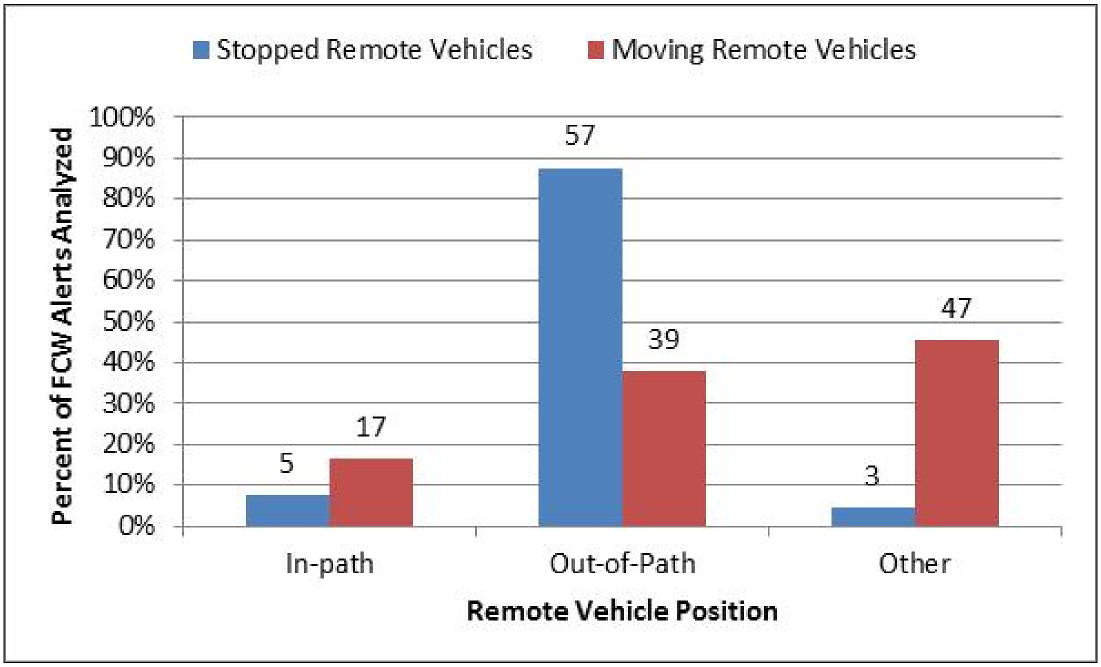


Figure 9. FCW RV Position by RV Motion – RSD1s

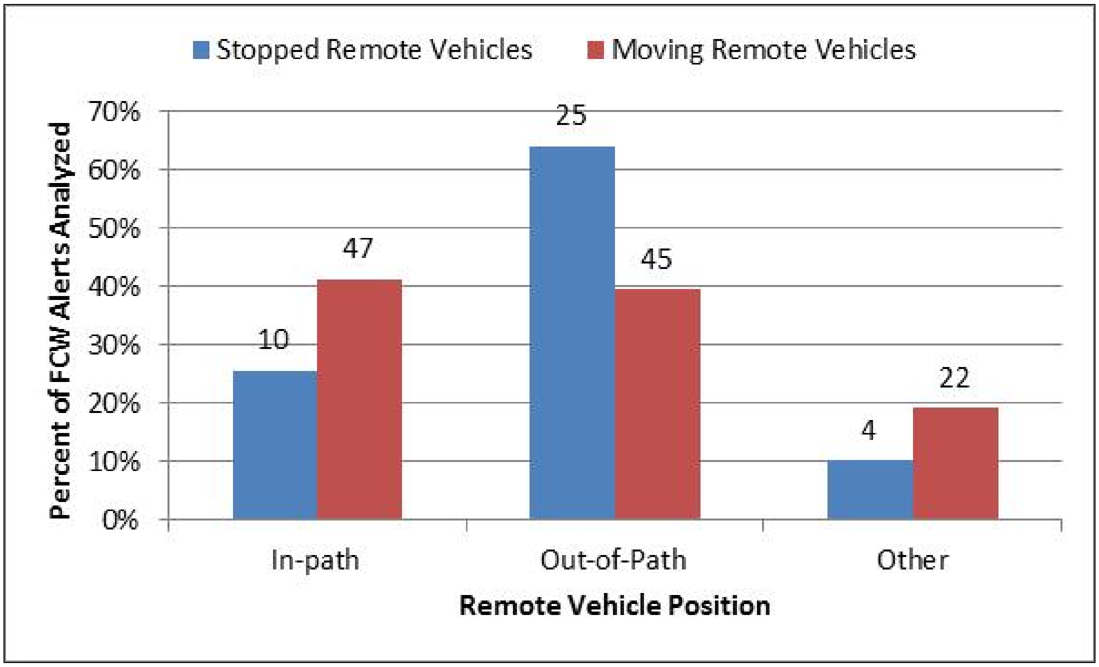


Figure 10. FCW RV Position by RV Motion – Integrated Truck #15501

3.2.1.1.4 FCW Alert Performance by Rear-End Driving Conflict

To assess the impact of driving conflicts on alert performance, the FCW performance data were broken down by three rear-end driving conflicts. These three conflicts, listed below, were determined based on analysis of video and numerical data within three seconds of alert onset. Limited numerical data collected from the RSD2s precluded a breakdown of rear-end driving conflicts.

- LVD – Lead vehicle decelerating
- LVS – Lead vehicle stopped
- LVM – Lead vehicle moving at a slower constant speed

Figure 11 and Figure 12 show rear-end driving conflict type by FCW RV position for RSD1s and integrated truck #15501 respectively. It should be noted here that 66 FCW events extracted from the RSD1s contained unknown pre-crash scenarios and therefore, were not included in the analysis. As shown in Figure 11, the majority of the in-path alerts were issued during the LVD scenarios. Thirty-nine percent of the alerts issued during LVD scenarios were for in-path RVs. Figure 12 shows the same trend of in-path alerts across the rear-end conflict types as was observed in Figure 11. Fifty-seven percent of the alerts issued during LVD scenarios were for in-path RVs. Forty-five FCW events extracted from the integrated truck #15501 contained unknown pre-crash scenarios and therefore, were not included in the analysis.

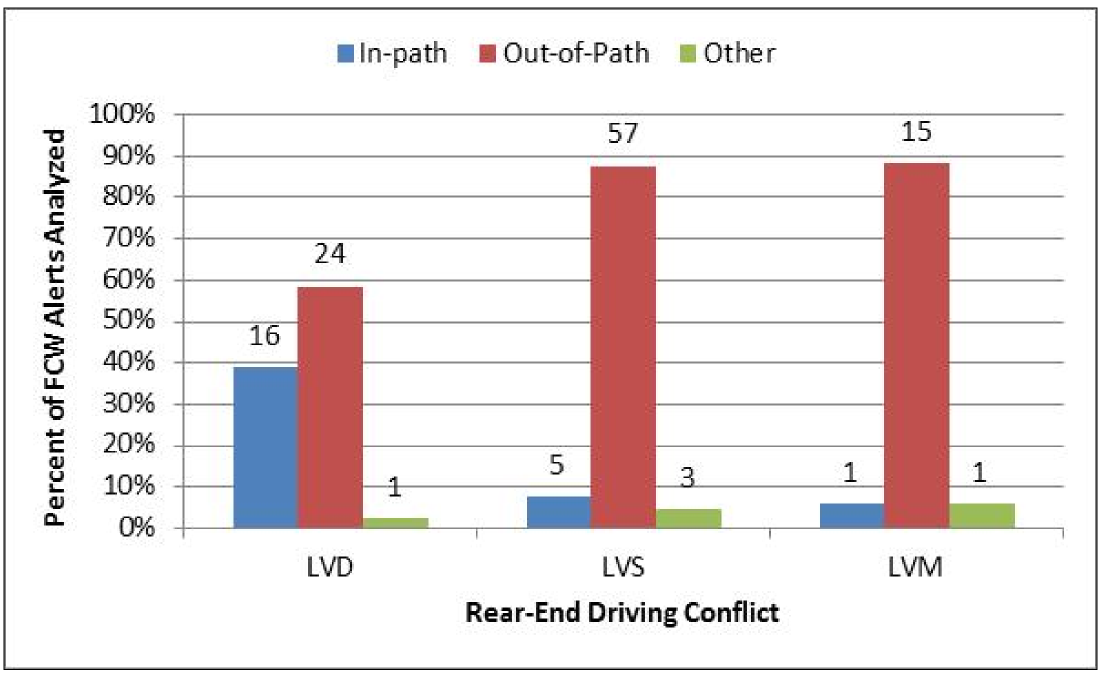


Figure 11. Rear-End Driving Conflict Type for FCW Alerts by RV Position – RSD1s

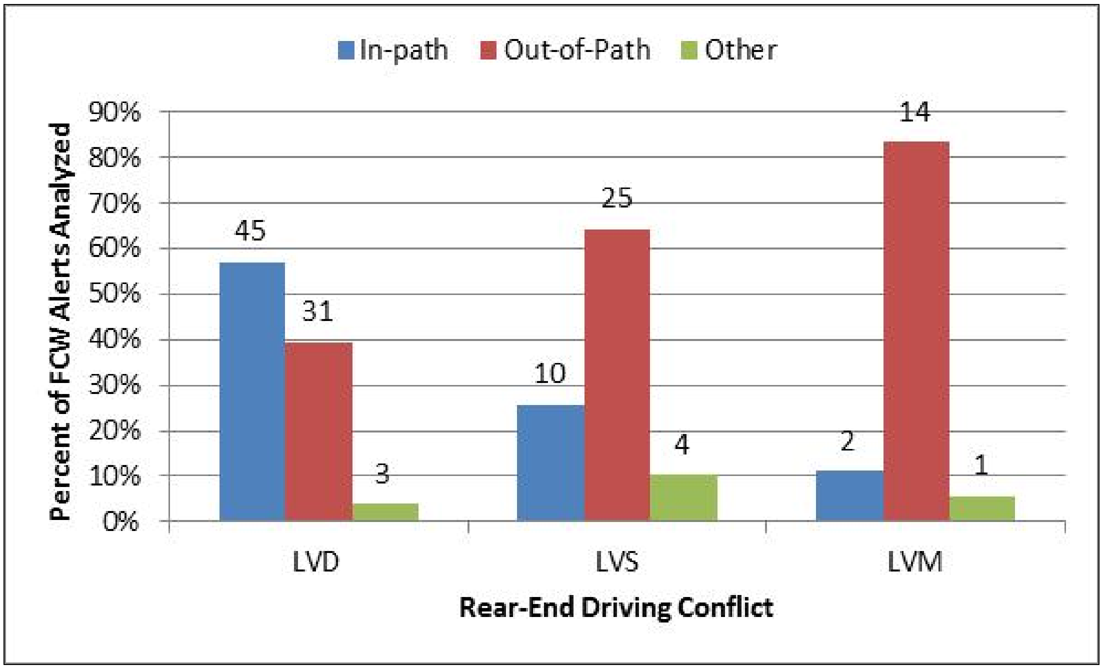


Figure 12. Rear-End Driving Conflict Type for FCW Alerts by RV Position – Integrated Truck #15501

3.2.1.1.5 FCW Alert Performance by Road Curvature

To understand the impact of road curvature on the FCW application performance, the data were broken down by whether or not the RV was traversing a curved road segment at the time of the alert.[5] Road curvature can create difficulties in determining lane-level accuracy, as RVs that are in-lane on a curved road may appear to be out-of-path to the FCW application. In addition, the HV position, (e.g., approaching the curve on a straight road, in-curve entry, or in-curve) may make a difference in performance. There were no alerts issued on curves by the RSD2s.

Figure 13 and Figure 14 show the breakdown of FCW RV locations by road curvature for the RSD1s and the integrated truck #15501 respectively. It should be noted here that FCW events with unknown road curvature information (28 events for the RSD1s and 12 events for the integrated truck #15501 were not included in the analysis. Note that percentages for each field do not add up to 100 percent as the "other" field for RV location is not displayed. In scenarios where the RV could not be located or was not directly ahead on the same roadway, RV location within the curve is not recorded.

As shown in Figure 13, the RV in- and out-of-path percentages were similar for RVs on straight roads and on curves. Figure 14 shows a greater disparity (38% compared to 8%) in percentages of in-path RVs for RVs on straight roads compared to those on curves. Table 7 shows a breakdown of the FCW alerts on curves by HV and RV locations for the RSD1s and integrated truck #15501. As shown in Table 7, one of four alerts was issued in-path when the HV equipped with the RSD1 was located at the curve entry and the RV was located in the curve. One of ten alerts was issued in-path when the HV equipped with the RSD1 was approaching on a straight road and the RV was located in the curve. In regard to the integrated truck #15501, one of four alerts was issued in-path when both HV and RV were located in the curve. One of eight (12.5%) alerts was issued in-path when the HV was approaching on a straight road and the RV was located at the curve entry. Overall, the percentages of in-path alerts issued on curves was greater when the HV was located at curve entry (RSD1) and in the curve (integrated truck #15501) compared to

[5] Road curvature was based on video analysis and inspection of the GPS location of vehicles on a map. All alerts issued on curved roads were on medium radius curves on surface streets (not freeway curves).

being located on the straight road approaching the curve. The percentages of alerts issued when the HV was approaching on a straight road were approximately the same for both RSD1s and integrated truck #15501.

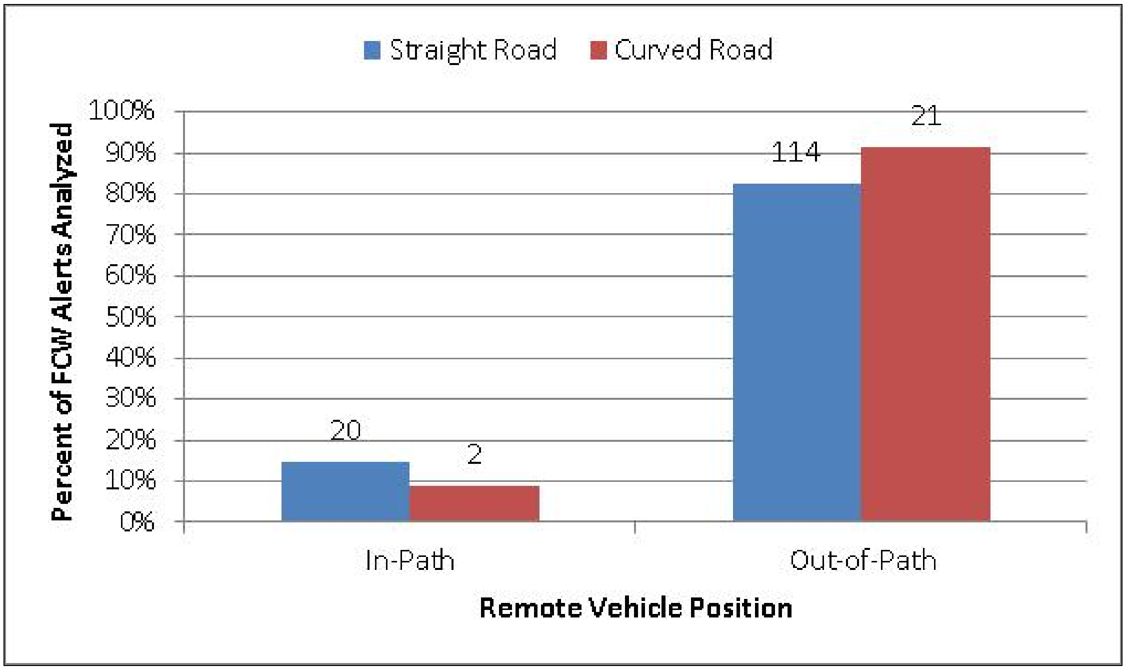


Figure 13. RV Position for FCW Alerts by Road Curvature (RSD1s)

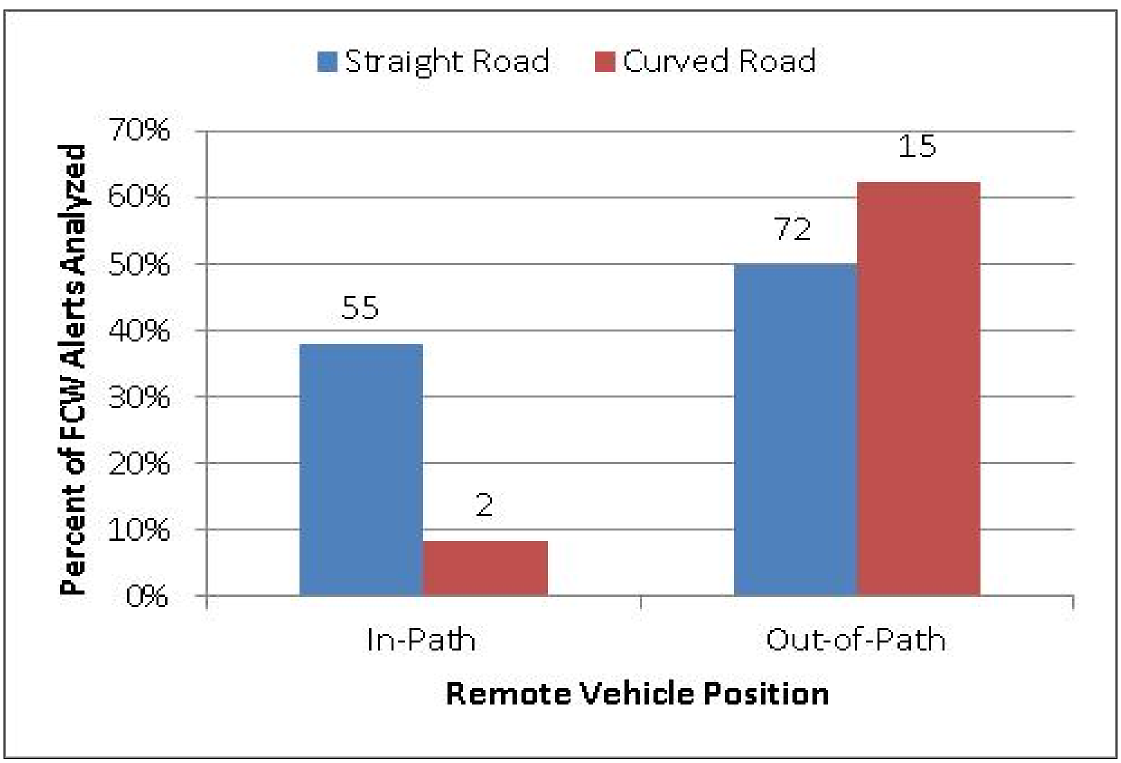


Figure 14. RV Position for FCW Alerts by Road Curvature (Integrated Truck #15501)

Table 7. FCW Alerts on Curves by HV and RV Locations for RSD1s and Integrated Truck #15501

Device	RV Position	RV Location	HV Location	Out-of-Path Alerts	In-Path Alerts	Total
RSD1s	Out-Of-Path	Curved Road	Curve entry	3[6]	1	4
			Curve exit	2[7]	0	2
			In-curve	7[8]	0	7
			Straight road	9[9]	1	10
Integrated Truck #15501	Out-Of-Path	Curved Road	Curve entry	5[10]	0	5
			In-curve	3[11]	1	4
			Straight road	7[12]	1	8

3.2.1.1.6 FCW Alert Performance by RV Range

The performance of the FCW application was broken down by the range at which the alerts were issued, to gain insight into whether the lane-level performance varied depending on how far away the RV was. Due to limited numerical data, RV range data was not available from the RSD2s.

Figure 15 and Figure 16 shows the performance of the alerts by range for the RSD1s and integrated truck #15501 respectively. It should be noted here, that 28 FCW events had unknown range values for the RSD1s and 12 FCW events had unknown range values for the integrated truck #15501; therefore these were not included in the analysis. As shown in Figure 15, alerts issued for RVs between 30 and 60 m away had the highest in-path percentages. Alerts farther away were more likely to be issued for out-of-path RVs. This suggests that the lane level position performance of the FCW application is best between these ranges. Figure 16 shows the performance of the alerts by range for the integrated truck #15501. As was observed in the previous figure, alerts issued for RVs between 30 and 60 m away had the highest in-path percentages.

[6] RV was located in-curve for all three FCW out-of-path events and one FCW in-path event.
[7] RV was located at curve exit for both of the FCW out-of-path events.
[8] RV was located in-curve for five of seven FCW out-of-path events and at curve exit for the remaining two events.
[9] RV was located in-curve for eight of nine FCW out-of-path events and at curve entry for the remaining event. RV was located in-curve for one FCW in-path event
[10] RV was located in-curve for all five FCW out-of-path events.
[11] RV was located in-curve for all three FCW out-of-path events and one FCW in-path event.
[12] RV was located in-curve for six of seven FCW out-of-path events and at curve entry for the remaining event. RV was located at curve entry for one FCW in-path event.

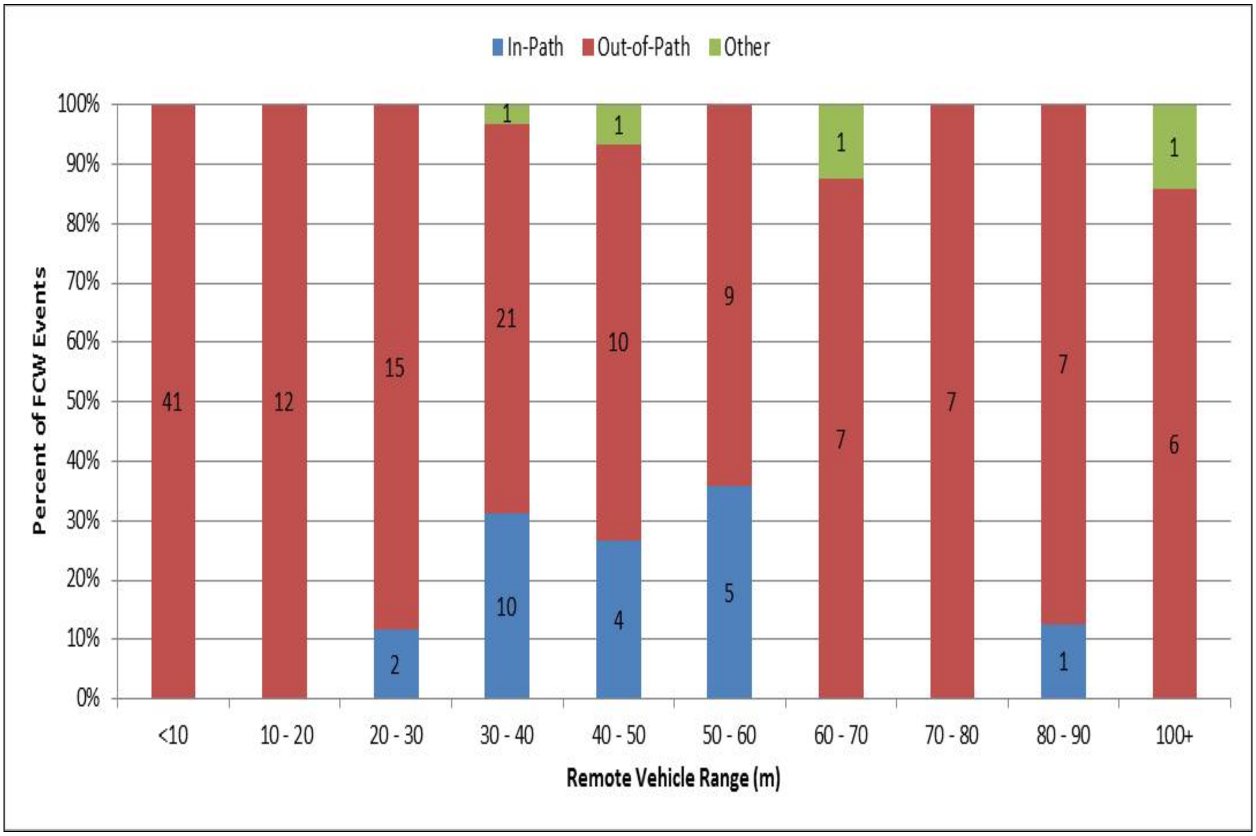


Figure 15. RV Position for FCW Alerts by RV Range (RSD1s)

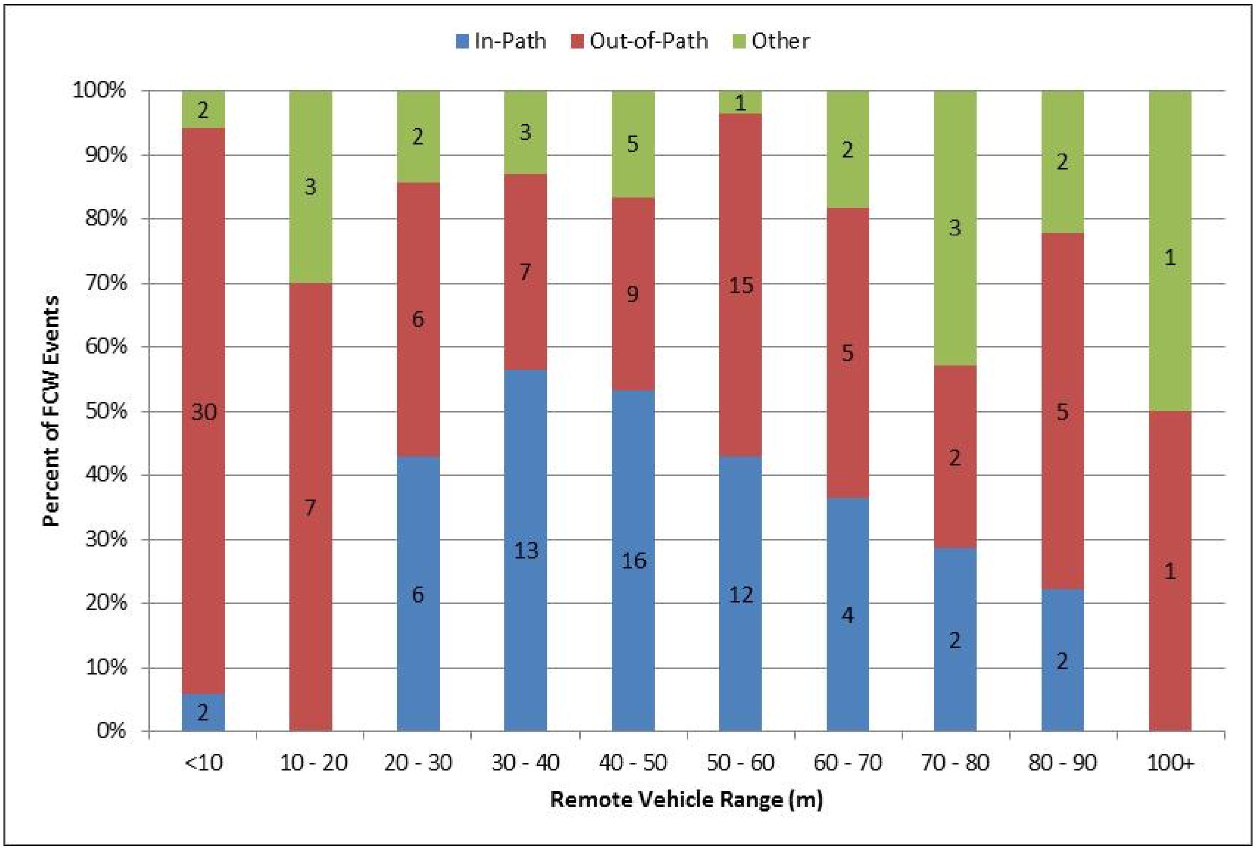


Figure 16. RV Position for FCW Alerts by RV Range (Integrated Truck #15501)

3.2.1.1.7 FCW Alert Performance by RV Device Type

Finally, Volpe assessed retrofit and integrated device performance as RVs. A safety application's ability to issue alerts correctly depends on the performance of the data it is receiving from the RV. If a RV is broadcasting incorrect, incomplete, or untimely information, it can trigger false alerts in surrounding vehicles. While integrated light vehicles used center-mounted roof antenna, the integrated truck #15501 and RSD1s used antennas mounted on the rear of the cab. The aftermarket devices (both ASDs and VADs) used a variety of antenna types and locations. Limited numerical data collected from the RSD2s precluded this information from being obtained.

To understand the impact that various antenna configurations and devices have on the performance of the RSD1 and integrated truck #15501 FCW alerts, Figure 17 and Figure 18 break down the performance of RSD1 and integrated truck #15501 FCW alerts by other RV device types, respectively. As shown in Figure 17, nine of the RSD FCW alerts were triggered by other RSD1 equipped trucks with seven (78%) in-path alerts. Fifteen RSD FCW alerts were triggered by ASDs; three (20%) alerts were in-path while 156 alerts were triggered by VADs. Of these 156 alerts, 12 (8%) were in-path. In addition, there were six RSD FCW alerts triggered by buses and 3 FCW alerts triggered by IVs. Overall, there was a large disparity (78% compared to 9%) in percentages of in-path alerts triggered by RSD1 equipped trucks compared to in-path alerts triggered by ASDs and VADs combined.

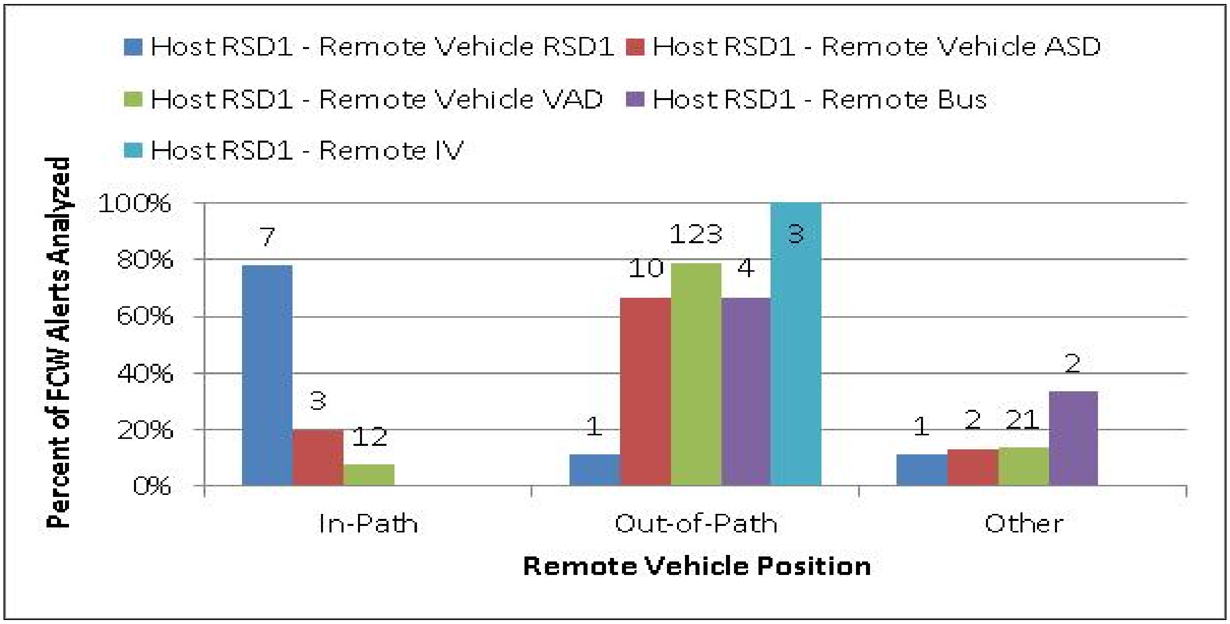


Figure 17. Breakdown of RSD1 FCW Alert Performance by RV Device Type

As shown in Figure 18, 17 of the integrated truck #15501 FCW alerts were triggered by other integrated trucks with 16 (94%) in-path alerts. Fourteen integrated truck #15501 FCW alerts were triggered by ASDs; 3 (21%) alerts were in-path while 149 alerts were triggered by VADs. Of these 149 alerts, 38 (26%) were in-path. The trends observed in Figure 18 are similar to those in Figure 17. Overall, there was a large disparity (94% compared to 25%) in percentages of in-path alerts triggered by remote integrated trucks compared to in-path alerts triggered by ASDs and VADs combined.

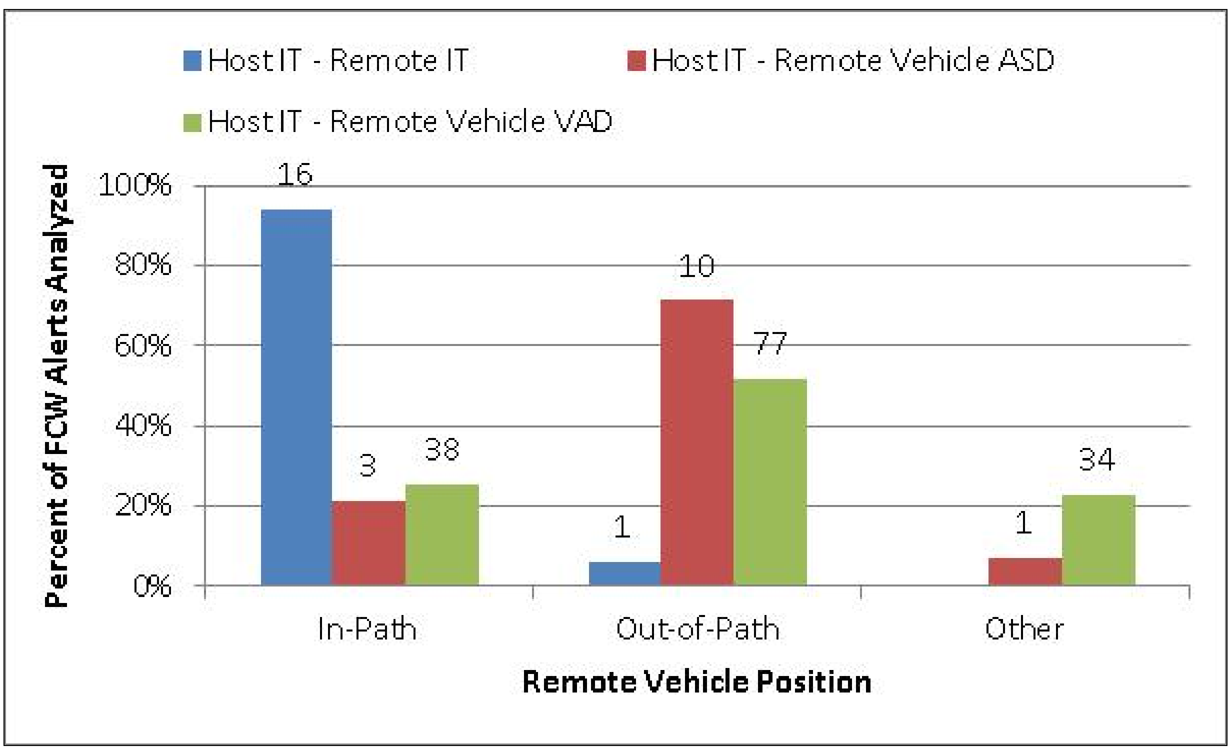


Figure 18. Breakdown of Integrated Truck #15501 FCW Alert Performance by RV Device Type

3.2.1.2 FCW Missed Alerts

Using the algorithm described in Section 3.1.2.1 and video validation of the results, one event, extracted from the RSD1 data, was identified as a potential missed FCW alert scenario. This event had a RV which was decelerating. The vehicle dynamics for the potential missed FCW alert scenario was compared to the vehicle dynamics of observed FCW alerts to confirm that the scenarios were similar.

Figure 19 shows TTC versus HV speed for FCW alerts with decelerating RVs, as well as the TTC versus speed trajectory for the one potential missed FCW alert with decelerating RV. Figure 20 shows the same events but compares time headway to HV speed. Since LVD scenarios are triggered by deceleration, there is sometimes not a significant closing speed at the time of the event. Headway does not depend on closing speed and provides an alternative measure for the timing of the alert. Both comparisons showed that the trajectory of the vehicle dynamics in the missed alert scenario was consistent with the observed dynamics of the FCW alerts issued for decelerating RVs.

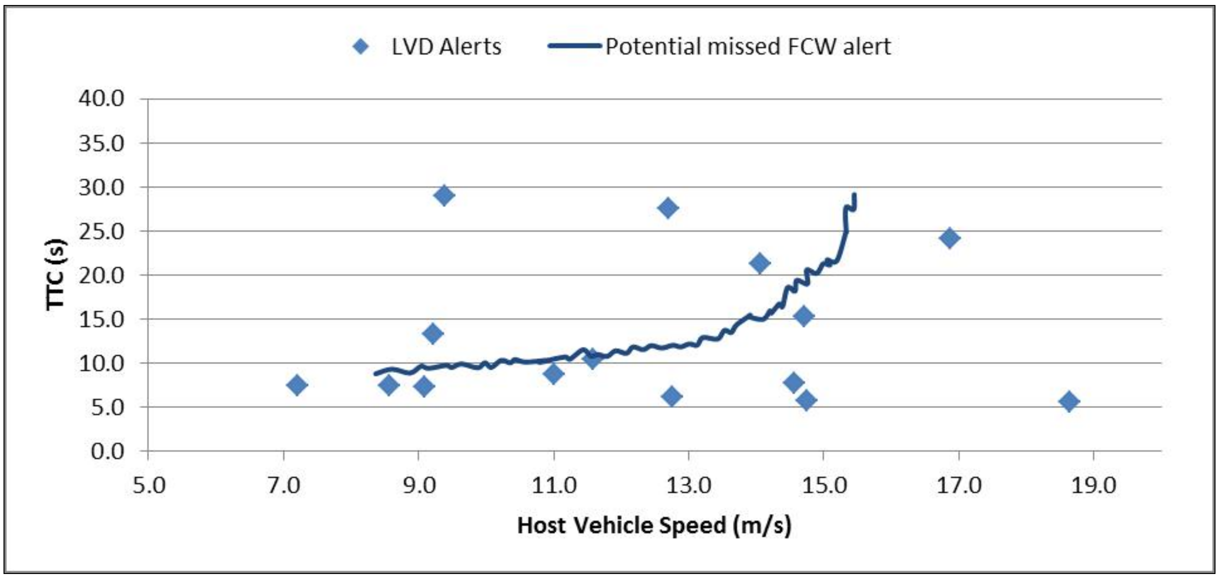


Figure 19. Comparison of TTC for FCW Alerts and Potential Missed FCW Alert with Decelerating RVs – RSD1s

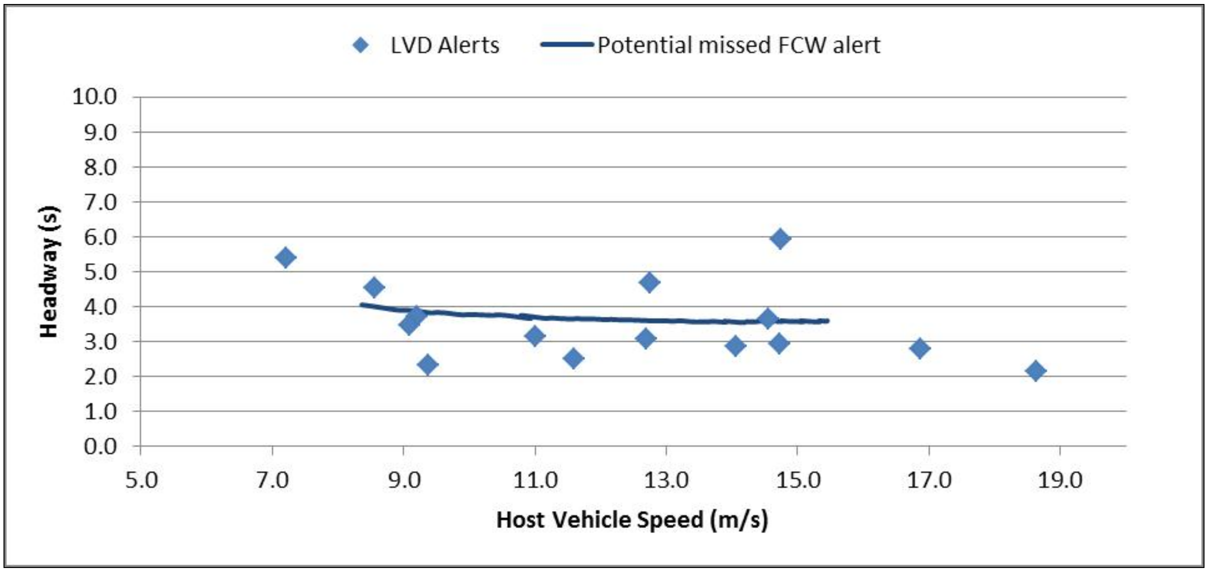


Figure 20. Comparison of Time Headway for FCW Alerts and Potential Missed FCW Alert With Decelerating RVs – RSD1s

3.2.2 IMA Results

3.2.2.1 This subsection presents alert performance and missed alert analysis results for the IMA application. The IMA safety application issues an alert to the participants when: 1) they are approaching (i.e., IMA Moving) or stopped (i.e., IMA Stopped) at an intersection with the intent to proceed, and 2) there is a potential collision threat with another vehicle approaching from a lateral direction. Application performance for IMA is based on the location of the HV relative to an intersection where the alert was issued. IMA Alert Performance

Figure 21 shows the overall breakdown of alert location for the IMA alerts issued by the integrated truck #15501 and the RSD1s. There were 638 IMA alerts issued by the integrated truck (342 alerts) and RSD1s (296 alerts). Table 8 provides definitions for the alert location categories listed in Figure 21. Table 8 also illustrates each category. In the diagrams, the green arrow represents the HV and the red arrow represents the RV. Any alert that did not fall into the "Intersection" category was considered a false alert. "Other" refers to events where an RV could not be identified (including events with no forward video), was off the roadway or not positioned appropriately for an IMA alert (e.g., in an adjacent parking lot, on a lateral roadway, or traveling the opposite direction).

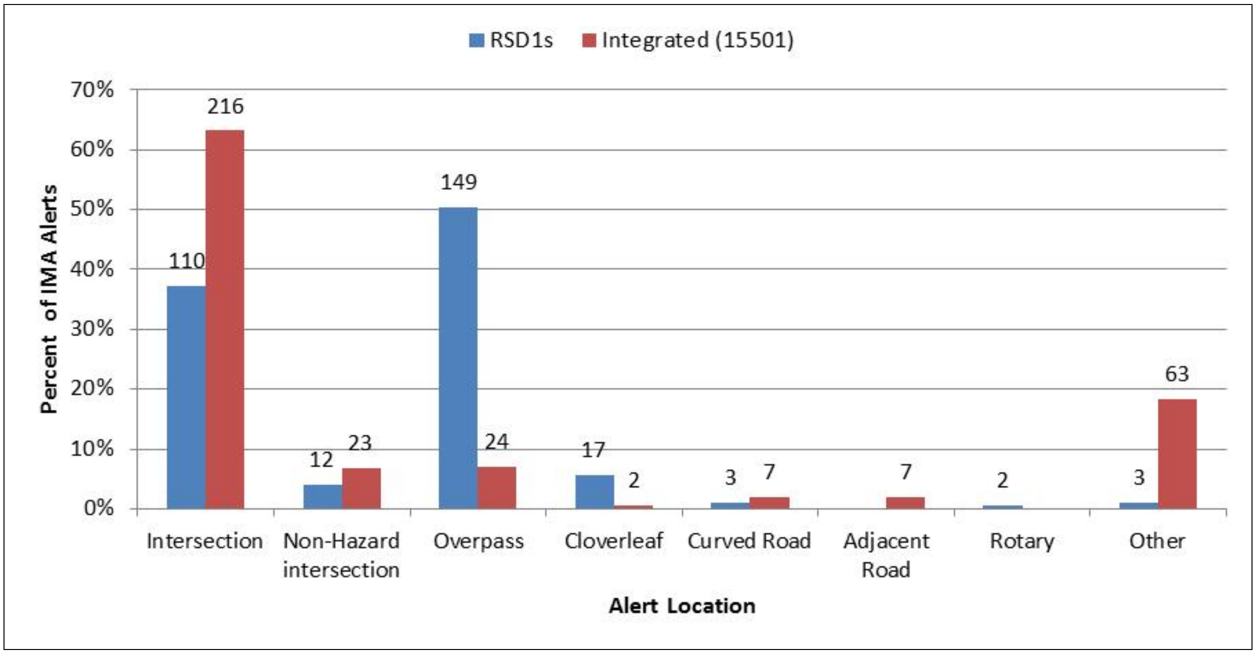
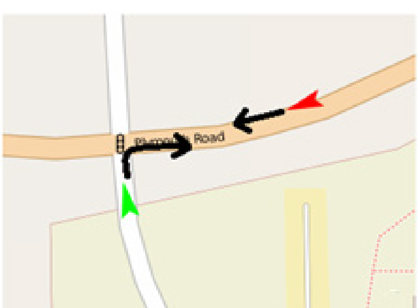
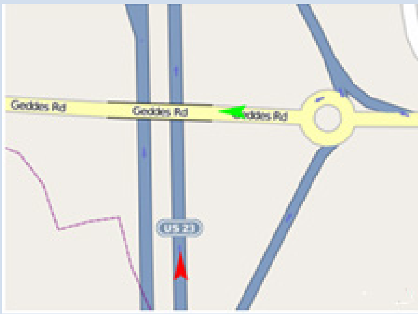
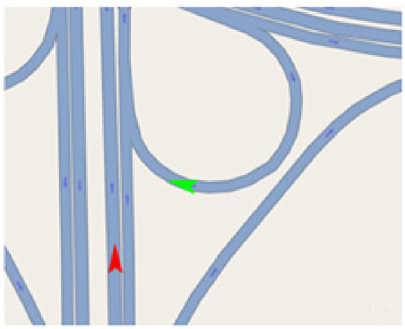
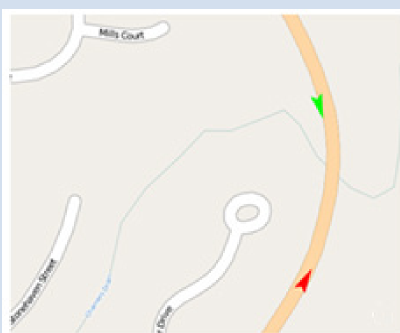
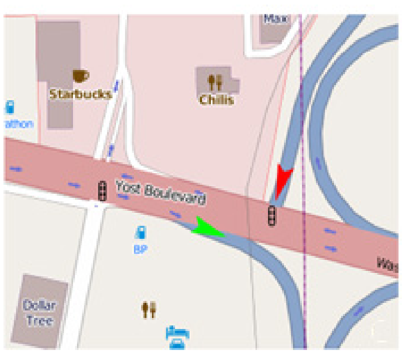


Figure 21. Breakdown of IMA Warning Location by Device Type

Table 8. IMA Alert Scenarios

Alert Location	Description
Intersection 	Alert is issued while the HV is approaching, or stopped at an intersection, and in a potential hazard scenario (the paths of the HV and RV intersect).
Intersection, Non-Hazard 	Alert is issued while the HV is approaching, or stopped at an intersection. Due to the relative vehicle locations and paths of travel, the RV is not a threat. (Generally these are scenarios where the HV is making a right turn, and the RV is approaching from the right.)

Alert Location	Description
Overpass 	Alert is issued in a scenario where the paths of the HV and RV will not intersect because one path goes over an overpass.
Cloverleaf 	Either the HV or RV[13] is traversing a cloverleaf at the time of the alert.
Curved Road 	The HV and the RV are approaching each other from opposite directions on a curved road.
Adjacent Road 	The RV is on a road that does not intersect with the road the HV is on.

[13] Remote vehicle: the vehicle triggering the safety application alert.

Alert Location	Description
Rotary 	The HV is approaching, or navigating a rotary.

- The percentage values of IMA alerts that occurred at intersections were 37 percent and 63 percent for the RSD1s and integrated truck #15501 respectively.
- The majority of the false alerts (50% of all IMA alerts) issued by the RSD1s occurred at an overpass. The percentage of false alerts issued at an overpass by the integrated truck #15501 was small (7%). This could be attributed to the UMTRI drivers driving in areas where there were no overpasses. It could also be due to the fact that the integrated truck #15501 system accounts for elevation in GPS data.

It should be noted here that upon receiving the alert, the driver took the appropriate action. There were no crashes in this study.

3.2.2.1.1 IMA Alert Performance by RV Device Type

Figure 22 and Figure 23 break down the performance of RSD1 and integrated truck #15501 IMA alerts by other RV device types, respectively. As shown in Figure 22, the majority of the RSD1 IMA alerts issued at intersections were triggered by VADs and ASDs. There were 260 IMA alerts triggered by VADs with 95 (37%) alerts issued at intersections. Twenty-six RSD1 IMA alerts were triggered by ASDs; 11 (42%) alerts were issued at an intersection. The majority of the false alerts triggered by VADs (50%) and ASDs (58%) were issued at an overpass. Overall, the percentages of alerts triggered by VADs and ASDs at intersections, are approximately the same.

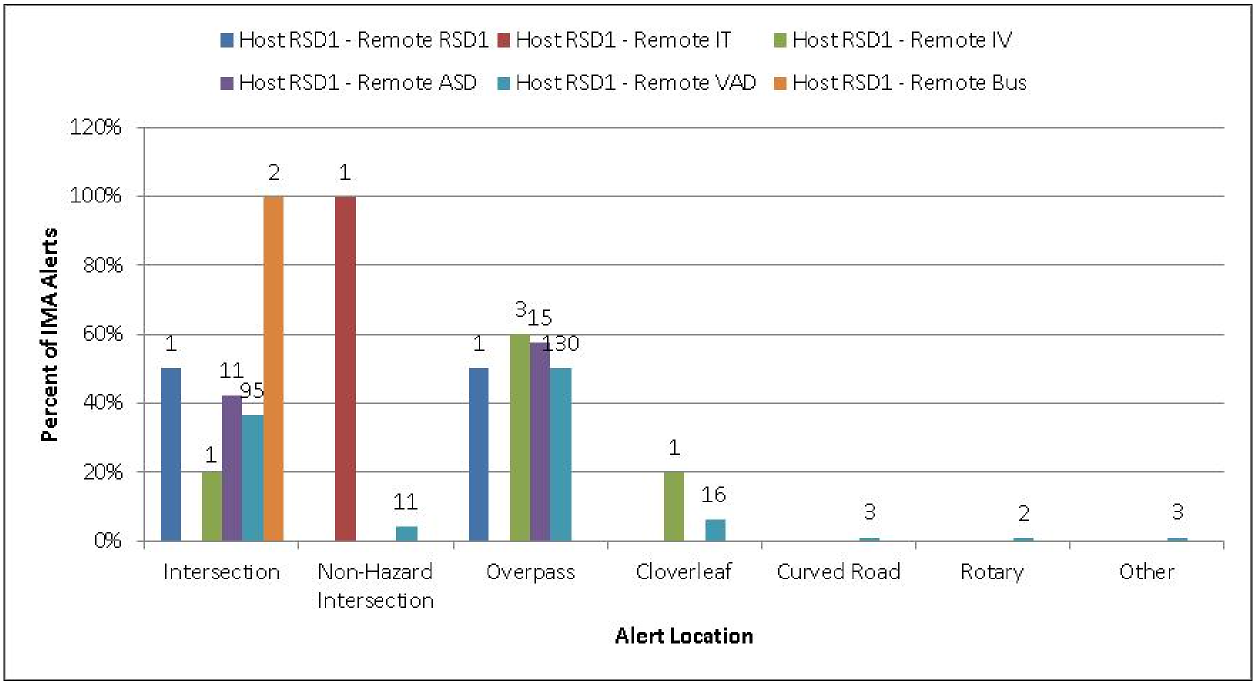


Figure 22. Breakdown of RSD1 IMA Alert Performance by RV Device Type

As was observed in Figure 22, the majority of the integrated truck #15501 IMA alerts (Figure 23) issued at intersections was triggered by VADs and ASDs. There were 295 integrated truck IMA alerts triggered by VADs with 188 (64%) alerts issued at intersections. Twenty-six IMA alerts were triggered by ASDs; 19 (73%) alerts were issued at an intersection. In addition, 12 IMA alerts were triggered by IVs; 7 (58%) alerts were issued at an intersection. There were fewer false alerts triggered at an overpass by the VADs compared to the totals shown in Figure 22. As stated previously, this could be attributed to the UMTRI drivers driving in areas where there were no overpasses. It could also be due to the integrated truck #15501 system accounting for elevation in GPS data. Overall, the percentages of alerts triggered by VADs and IVs at intersections, are approximately the same.

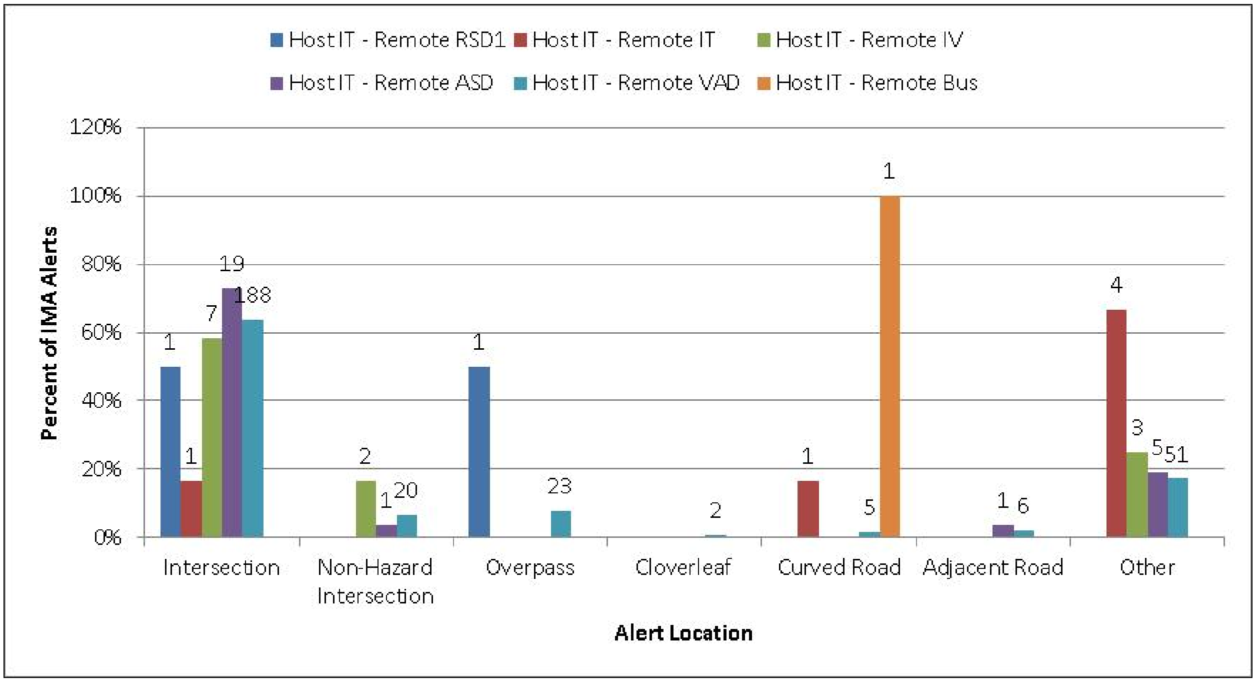


Figure 23. Breakdown of Integrated Truck #15501 IMA Alert Performance by RV Device Type

3.2.2.2 IMA Missed Alerts

The following subsection discusses results of the analysis of missed IMA alerts.

3.2.2.2.1 IMA Stopped

Using the algorithm described in Section 3.1.2.2 and video validation of the results, one event extracted from the RSD1 data, was identified as a potential missed IMA alert scenario. The relative vehicle dynamics of the HV and RV were within the parameters of observed IMA stopped alerts, but an alert was not issued.

Figure 24 shows the RV's target time-to-intersection versus RV range at the onset of the IMA alerts, as well as the TTI versus range trajectory for the one potential missed IMA alert. The one potential missed alert event was within the range and TTI values observed in the IMA alerts.

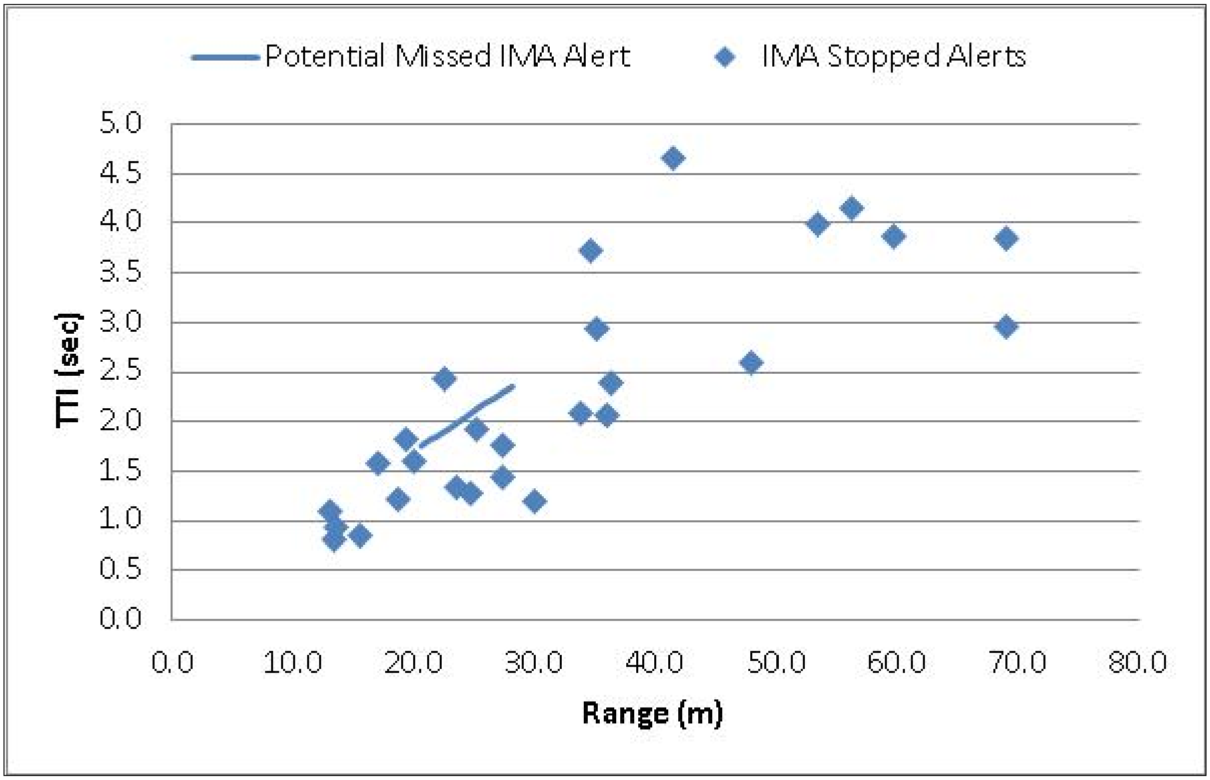


Figure 24. Comparison of TTI for IMA Stopped Alerts and Potential Missed IMA Alert - RSD1s

3.2.2.2.2 IMA Moving

Examination of videos of IMA moving scenarios did not yield any potential missed IMA alerts.

3.2.3 BSW/LCW Results

3.2.3.1 This subsection presents results of alert performance for the BSW/LCW safety application. The BSW/LCW safety application alerts participants to the presence of vehicles in their blind spot and warns them if turn signal is activated for lane change. It should be noted here that the RSD1s were equipped with BSW only (cautionary alert with no audio) and the integrated truck #15501 was equipped with both BSW/LCW. The RSD2s were not equipped with BSW/LCW. The analysis of the cautionary alerts involved examining scenarios where the turn signal was activated and the RV was present in the adjacent lane. BSW/LCW Alert Performance

Figure 25 shows the RV location of the 15 BSW/LCW alerts analyzed. It should be noted that “Other” refers to events that have no video or where the RV could not be located.

- Eighty-eight percent of BSW alerts issued by the RSD1s were for RVs in the adjacent lane. None of the events involved a steering response from the driver.
- Seventy-one percent of BSW/LCW alerts issued by the integrated truck #15501 were for vehicles in the adjacent lane. None of the events involved a steering response from the driver.

It should be noted that upon receiving the alert, the driver took the appropriate action. There were no crashes in this study.

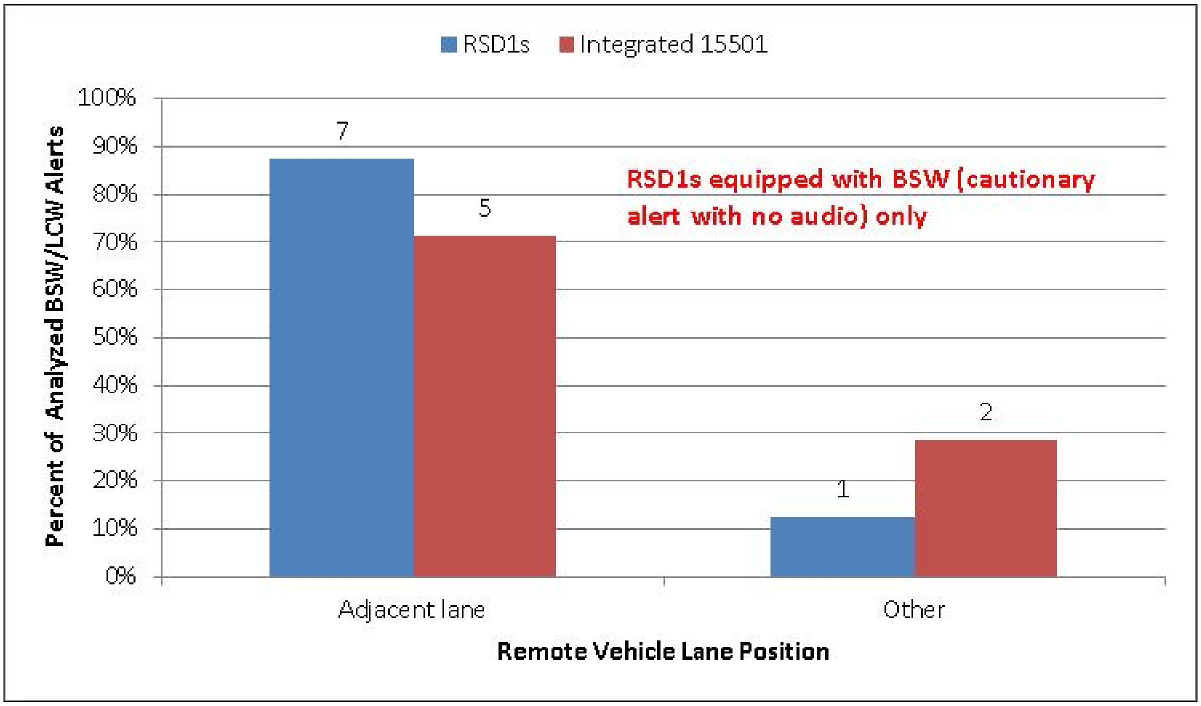


Figure 25. BSW/LCW RV Position

3.2.3.2 BSW/LCW Missed Alerts

Using the algorithm described in Section 3.1.2.3 and video validation of the results, one event, extracted from the integrated truck #15501 data, was identified as a potential missed LCW alert scenario. This event had a RV in the adjacent lane along with turn signal activation.

3.2.4 EEBL Results

3.2.4.1 This subsection presents results of alert performance for the EEBL safety application. The EEBL safety application alerts participants to heavy braking ahead in the traffic queue. There were no EEBL alert data collected from the RSD2s. EEBL Alert Performance

Figure 26 shows the RV location of the 20 EEBL alerts analyzed. It should be noted that "Other" refers to events where the analysts were not able to locate the RV.

- The majority of the alerts (73%) issued by the RSD1s were for in-path and adjacent lane RVs. Two of the eleven events involved an obstructing lead vehicle.
- All of the alerts issued by the integrated truck #15501 were for in-path RVs. One of the five events involved an obstructing lead vehicle.

It should be noted that upon receiving the alert, the driver took the appropriate action. There were no crashes in this study.

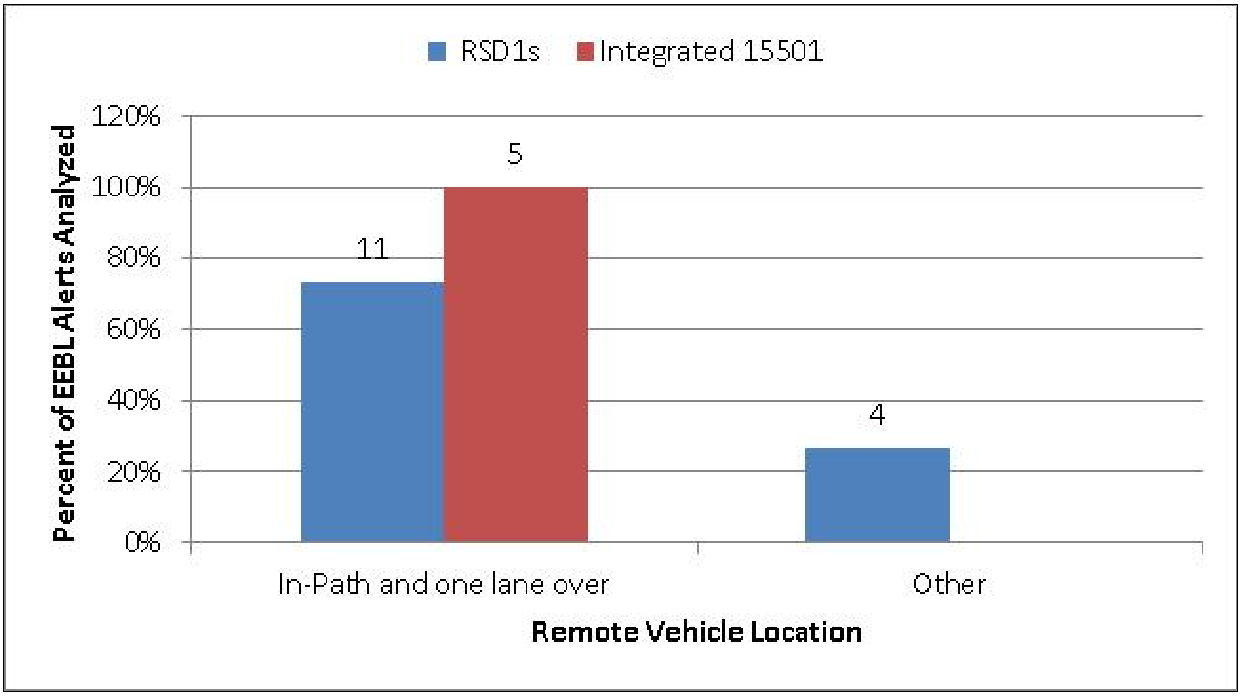


Figure 26. EEBL RV Position

3.2.5 CSW Results

3.2.5.1 This subsection presents results of alert performance for the CSW safety application. The CSW safety application alerts participants when approaching a curve at a speed higher than indicated by the RSE. It should be noted here that all the alerts analyzed were issued by the RSD1s. There were no CSW alert data collected from the RSD2s and integrated truck #15501. CSW Alert Performance

Figure 27 shows the HV locations (e.g., curve entry, in-curve, curve exit, etc.) of the CSW alerts analyzed. The majority of the alerts were issued at the entry points to equipped curves located on Plymouth Road (71%) and Bonisteel Boulevard (65%).[14] The percentage values of CSW alerts issued in the equipped curves located on Plymouth Road and Bonisteel Boulevard were 12 percent and 35 percent respectively. Other denotes alerts issued at non-instrumented locations. The percentage of CSW alerts issued at curve entry and in the equipped curve on both Plymouth Road and Bonisteel Boulevard combined is 91 percent. It should be noted that upon receiving the alert, the driver took the appropriate action. There were no crashes in this study.

[14] Plymouth Road and Bonisteel Boulevard are located in the SPMD area.

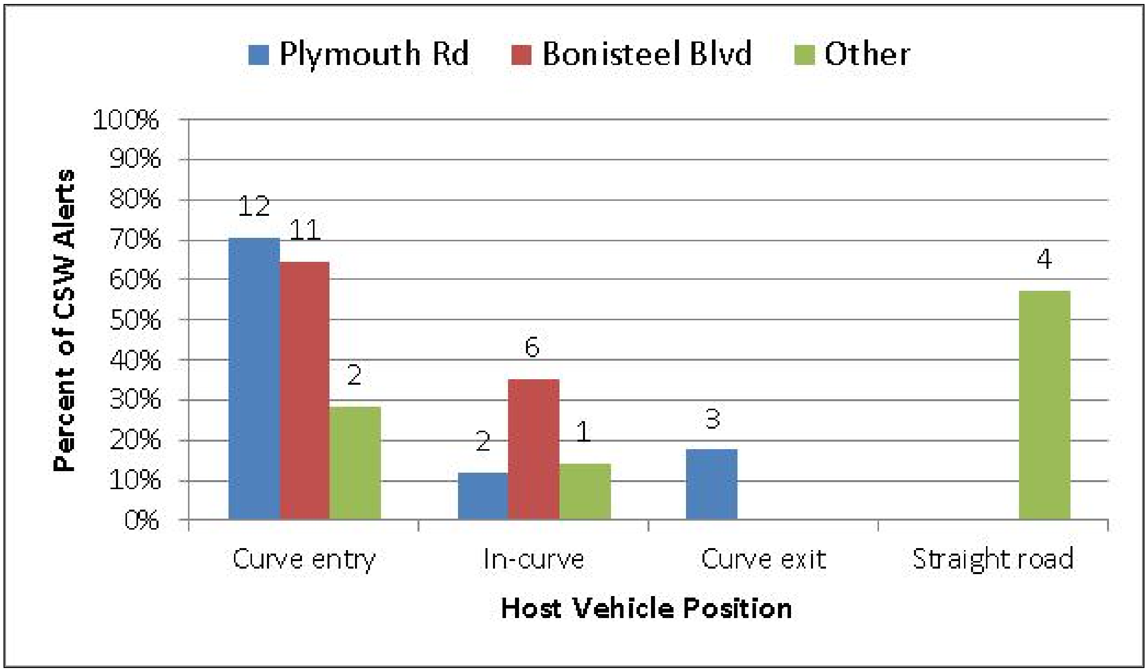


Figure 27. CSW HV Position

Figure 28 and Figure 29 display the CSW alerts (curve entry and in-curve only) by vehicle speed at the Plymouth Road and Bonisteel Boulevard locations respectively. As shown in both figures all of the CSW alerts were issued at or above the threshold speeds. As shown in Figure 28, 2 of the 14 CSW alerts were issued in-curve. The remaining 12 alerts were issued at curve entry. It should be noted here that none of the CSW alert events involved the driver braking when the alert was issued. As shown in Figure 29, 6 of the 17 CSW alerts were issued in-curve. The remaining 11 alerts were issued at curve entry. None of the CSW alert events involved the driver braking when the alert was issued.

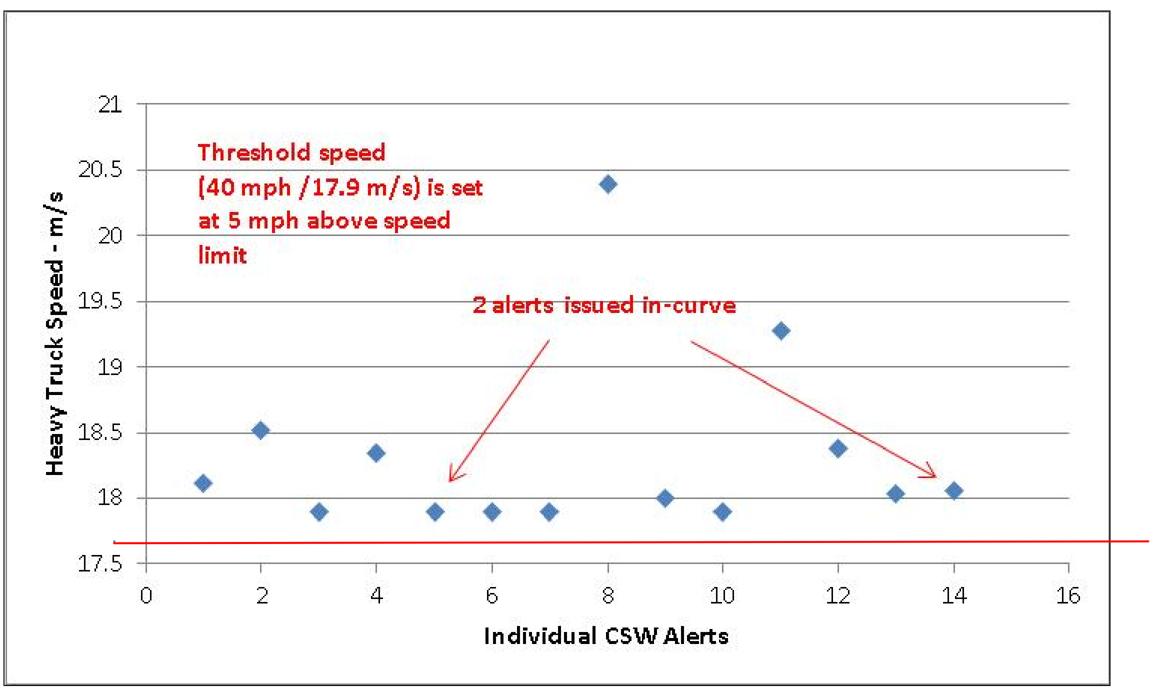


Figure 28. CSW Alerts Issued on Plymouth Road by HT Speed

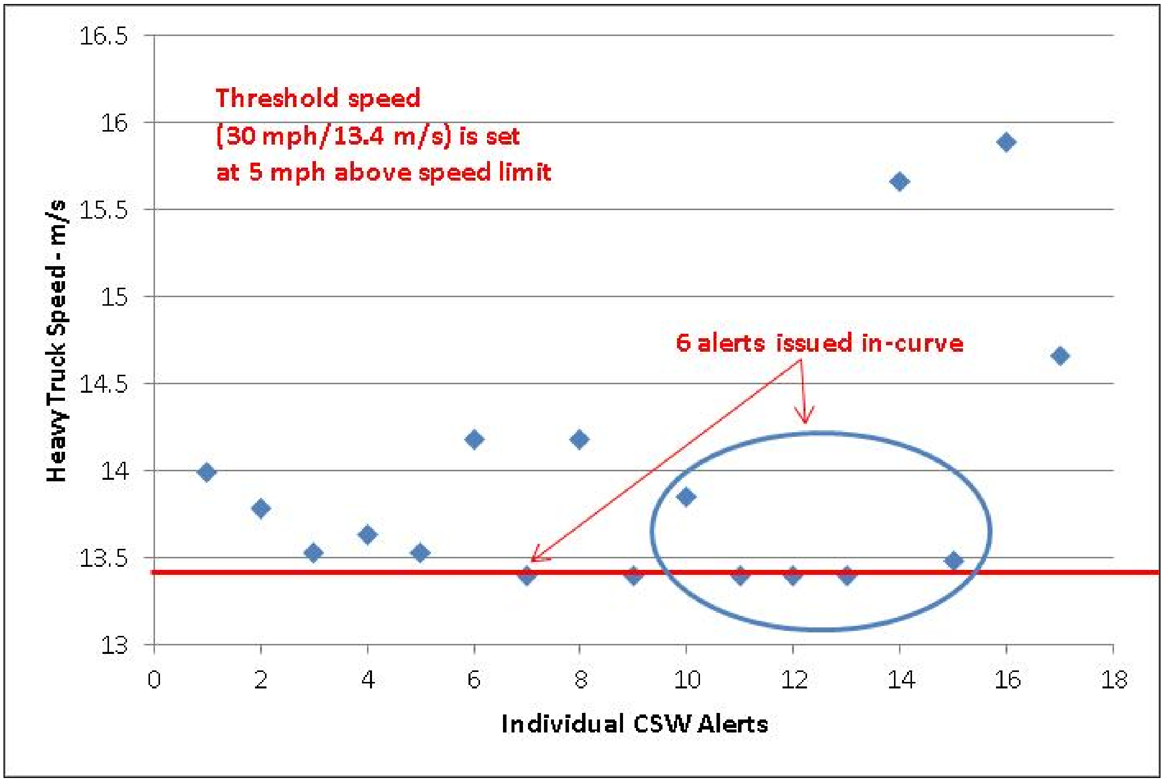


Figure 29. CSW Alerts Issued on Bonisteel Boulevard by HT Speed

3.2.5.2 CSW Missed Alerts

Using the algorithm described in Section 3.1.2.4 and video validation of the results, two events, extracted from the RSD1 data, were identified as potential missed CSW alert scenarios. The events occurred on the equipped curve on Plymouth Road. In both cases, the HV was entering the curve.

3.3 Summary of Results

Table 9 presents a summary of the percentage of valid alerts issued by each of the safety applications by device type. As shown in Table 9, the percentage values of FCW alerts issued for in-path RVs were 12 percent and 43 percent for RSD1s and RSD2s respectively, and 32 percent for the integrated truck #15501. The percentage values of IMA alerts issued at intersections were 37 percent and 63 percent for the RSD1s and integrated truck #15501 respectively. As noted in the table, the RSD2s were not equipped with IMA and BSW/LCW. Eighty-eight percent of BSW alerts issued by the RSD1s were for RVs in the adjacent lane. As noted in the table, the percentage of valid BSW alerts for RSD1 is for cautionary alerts only. Seventy-one percent of BSW/LCW alerts issued by the integrated truck #15501 were for vehicles in the adjacent lane. The majority of the EEBL alerts (73%) issued by the RSD1s were for in-path and adjacent lane RVs. All the EEBL alerts issued by the integrated truck #15501 were for in-path RVs. The percentage of valid CSW alerts issued at curve entry and in the equipped curve on both Plymouth Road and Bonisteel Boulevard combined is 91 percent.

Table 9. Percentage of Valid Alerts by Safety Application and Device

Percentage of Valid Alerts by Safety Application and Device			
	Integrated Truck #15501	**RSD1**	**RSD2**
FCW	32%	12%	43%
IMA	63%	37%	n/e[15]
BSW/LCW	71%	88%[16]	n/e
EEBL	100%	73%	n/d[17]
CSW	n/d	91%[18]	n/d

15 Denotes RSD2 not equipped with safety feature
16 Denotes percentage of valid BSW (cautionary alert with no audio) alerts
17 Denotes no data collected
18 The percentage is the sum of valid alerts (curve entry and in-curve) at both Plymouth Road and Bonisteel Boulevard

4 Unintended Consequences

With the introduction of new technology into a driving environment, there is always the potential that the technology will have unintended consequences that negatively impact driver safety. These consequences could be in the form of a negative behavioral adaptation over time, or a direct negative impact on driver behavior. The potential unintended consequences of the FCW and IMA safety applications were considered and examined. Unlike some studies that have distinct control (driver did not receive an alert) and treatment (driver did receive an alert) periods, the SPMD had distinct control and treatment vehicles, with control (unequipped) vehicles making up the majority of vehicles with which the HTs shared the road. This is relevant because studies with distinct periods provide a clean demarcation (time boundary) to examine changes in attention and other driving behavior. Rather than having this time boundary, the SPMD had a spatial demarcation, but the drivers had no advance knowledge concerning which vehicles were equipped and which were not. The lack of this knowledge and the absence of a time boundary mean we cannot analyze differences in driver behavior in a "before versus after" period or with equipped versus unequipped vehicles. The only differences we can analyze are those associated with alerts and their matching control events.

Despite the lack of a time boundary or spatial boundary in the experimental design, the data still supports analyzing some unintended consequences. Here we are looking for undesirable changes in HT driver behavior when they interacted with equipped vehicles. No such changes were observed. Thirty-seven crash-imminent alerts (i.e., 5 FCW and 32 IMA alerts) issued during potential hazard scenarios were examined. The data examined included:

- Response time to a decelerating or stopped RV (FCW)
- Deceleration level when responding to a decelerating or stopped RV (FCW)
- Deceleration level when approaching an intersection with an equipped RV approaching from a lateral direction (IMA)
- Driver attention around FCW and IMA alerts

4.1 FCW

Braking response times for three LVD and two LVS conflicts along with five matching control events were examined. The paired treatment alert and control event response times varied in terms of the treatment alert producing a faster response than that of the control event. There is thus no unintended consequence of how quickly drivers responded. In addition, peak deceleration levels for LVD and LVS conflicts when drivers were responding to the slower RV were also examined. The paired treatment alert and control event deceleration levels were generally very close to each other, so there was no increase in the deceleration level when drivers were alerted and no unintended consequence. In none of the five FCW conflicts did the driver appear startled or annoyed by the alert.

4.2 IMA

Examination of peak deceleration levels for 5 IMA treatment alerts and 14 matching control events in the moving scenario revealed generally lower magnitude levels for the control event compared to the matching treatment. Although the peak deceleration in the control events generally had a lower magnitude than that of the matching treatment, the differences were minor and the peak deceleration levels were below 1.7 m/s^2, a low level. No unintended consequence was observed in the deceleration levels of the drivers during the five IMA alert events nor did the drivers appear startled or annoyed by the alerts.

4.3 Driver Attention Around FCW and IMA Alerts

In the SPMD, the experimental design does not support detecting changes in driver attention associated with the presence of the RSD1. Lacking the time boundary or spatial boundary, claims such as “drivers paid less attention when the device was activated” or “drivers paid less attention when interacting with equipped vehicles” are not possible. Nevertheless, some discussion concerning driver attention around treatment alerts is in order. If drivers tend to be inattentive when they are alerted, this would suggest the RSD1 alerts helped them redirect their attention to a threat, a positive outcome. Table 10 lists the four RSD1 alert types, the quantity of each, and the quantity of distracted behavior (three types) observed around the alerts. During the 37 alerts issued during potential hazard scenarios, there were few instances of eyes off the driving task (2), drivers engaging in a secondary task (5), and drivers with their eyes off the threat (2). Based on these observations and tabulations, HT drivers were generally attentive when they received alerts. Therefore, the RSD1 safety applications were generally not needed to redirect their attention to the driving task and nearby threats.

Table 10. Driver Attention Around Treatment Alerts

Alert Type	Quantity	Eyes Off Driving Task	Engaging in Secondary Task	Eyes Off Threat
IMA moving	6	0	0	0
IMA stopped	26	0	3	0
FCW LVD	3	1	1	1
FCW LVS	2	1	1	1
Total	37	2	5	2

5 Driver Acceptance

This section describes the analysis of driver acceptance of the V2V and V2I safety applications for HTs in the SPMD, including both integrated systems and the RSDs. Also, this section defines the term "driver acceptance" and outlines the objectives of this analysis. The section ends with a brief description of the driver-vehicle interfaces used in the SPMD.

5.1 What is Driver Acceptance?

The precise definition of driver acceptance is complicated since it is made up of a variety of opinions, understandings, and attitudes that a driver may have towards a technological system used in vehicles. To add to the complexity, there can be a circular relationship between driver acceptance and system performance, because system performance affects acceptance and in turn, acceptance can influence performance. For example, a driver with low confidence in a system may ignore it, leading to a decrease in system safety benefits. On the other hand, a driver with too much confidence may over-rely on the system and pay less attention to the road; this overreliance can also lead to a decrease in safety benefits.

The different opinions, understandings, and attitudes a driver may have towards a piece of technology may vary independently of one another. For example, a driver might rate the understandability of a system high but have low confidence in its performance. In another example, the driver might rate the safety benefits of the system high but have concerns over data privacy. Understanding driver acceptance means looking at multiple factors individually to gain a more accurate understanding of what drivers like and, as far as possible, to understand why.

In this analysis, acceptance is defined based on driver perception of the following five factors:

- *Usability:* Is the technology easy to use and understand?
- *Perceived Safety Benefits:* Will the technology contribute to your driving safety?
- *Unintended Consequences:* Are you concerned about distraction or overreliance?
- *Desirability:* Do you want to have and use this technology in your vehicle?
- *Privacy:* How do you feel about privacy issues raised by this technology?

5.1.1 Analysis Objectives

The objectives of this analysis are to assess driver acceptance, defined in terms of the five factors listed in Section 5.1. In other words, understanding those five factors, and therefore overall acceptance, are the five objectives of this analysis.

Acceptance is shaped not only by preexisting opinions held by a given participant, but also by experience driving with the system in operation. For example, if a participant starts out with a high level of system acceptance and then experiences irritation with false alerts, their acceptance levels may decrease. On the other hand, another participant might start out distrusting the system and then experience a close call in which the system helps them avoid a collision, giving them a much higher level of acceptance. These relationships between experience and acceptance are lost when participants are averaged together. Volpe therefore explored the relationship between acceptance of the system and driving experience driver by driver. For example, survey responses were correlated with certain aspects of individual driver experience, such as the number of VMT and the number of alerts received.

5.2 Driver-Vehicle Interface

This section describes the DVIs used in the Integrated Trucks, and the RSD1 and RSD2 systems. The visual displays all consisted of a tablet mounted on the dashboard to the right of the driver (Figure 30).

Figure 30. Placement of the Display Screen in the Integrated Truck (left), RSD1 (middle), and RSD2 (right)

Table 11 shows the different caution and warning icons that were displayed on the screens of the different systems. These visuals were generally accompanied by auditory alerts. For the Integrated Truck and the RSD1, all applications had the same beeping sound, although it was longer in duration for the warning than for the caution. In the case of the BSW/LCW alert, where the BSW is a caution and the LCW is the warning, only the LCW had an auditory component. The RSD2 only had one type of alert and therefore only one type of sound for each application. However, for these the sound of the beeping varied between the different safety applications, allowing the driver to distinguish between applications based just on the sound.

Table 11. Caution and Warning Visual Displays

Application	Integrated Truck and RSD1	RSD2
EEBL		
FCW		
CSW		
BSW/LCW*		None

Application	Integrated Truck and RSD1	RSD2
IMA		None

The RSD1 only included the caution with no accompanying audio

5.3 Methodology

This subsection describes the methodology used to analyze the surveys completed by participants at the end of the study.

5.3.1 Likert-Scale Responses

Survey questions using a scale of 1 to 7 are inherently subjective since one participant's rating of 5 might be equivalent to another's 7. To remove some of this subjectivity, Volpe converted scores into one of three bins: "negative," "neutral," or "positive" (the actual names of these bins varied from question to question depending on the wording of each question). A conservative approach was taken with neutral scores: scores of 3 and 5 were counted as "neutral."

In general, the Likert-scale responses were displayed graphically as bar graphs showing the total results for groups of drivers; e.g., users of RSD1 or RSD2. In bar graphs, the number of participants who answered in a given category is listed within the bar.

5.3.2 Open-Ended Responses

Many of the survey questions include a space labelled "comments" for participants to write additional information in their own words. These responses are listed or summarized to illustrate and further explain the Likert-scale responses.

5.3.3 Statistical Approach

Parametric statistics, such as *t*-tests and analysis of variance, assume that the data are collected on an interval scale. These sorts of tests are not generally considered appropriate for data collected on a Likert scale because the magnitude of the difference between a response, for example a 4 and a 5, cannot be assumed to be the same as the magnitude of the difference between a 5 and a 6. Consequently, Volpe used non-parametric tests, such as Friedman, Mann-Whitney, Kruskal-Wallis tests, and Spearman correlations to analyze Likert-scale responses. The same reasoning lies behind using medians and interquartile ranges to describe central tendencies instead of means and standard deviations. On the other hand, where the data are on an interval scale, such as alert frequency, pricing of the system, or participant age, then parametric tests—such as *t*-tests, ANOVAs, and Pearson correlation tests—were used since they provide more statistical power.

All tests were two-tailed and statistical significance (alpha) was set at 0.05.

5.4 Survey Results

This section presents the results of the survey analyses. Results are presented first for the integrated trucks and then for the RSDs. RSD results are presented separately for RSD1 and RSD2 systems since the responses differed between the two.

In the survey, the V2V-based warning system is referred to as "Connected Vehicle (CV) technology."

5.4.1 Integrated Truck Results

Only one participant who used the integrated truck completed a survey. Since a quantitative analysis is not possible on a single subject, the participant's responses are summarized in the following bullets, broken down in terms of "overall impressions" and the five objectives of this analysis.

The participant spent 3 months using the system, from November 2012 to February 2013.

5.4.1.1 Overall Impressions

- What the participant liked *most* about the system were "the T-bone [IMA] and blind spot warnings." With regard to individual applications, the BSW/LCW was liked because "semis have large blind spots, loved the extra help." For the IMA, the participant said: "got the warning at a stop sign that had a blind curve at the intersection. Wonderful, worked great."
- What the participant liked *least* about the system was unclear. However, based on another response (see the second bullet in 5.4.1.2), it seems to be that audio alone cannot be used to tell what type of warning the system is issuing; "no audio warning that differentiates between."

5.4.1.2 Usability

- The participant thought it was clear why the system issued warnings when it did and trusted the overall system (and the BSW/LCW and IMA applications individually—the participant did not rate the EEBL, FCW, or CSW applications individually).
- Also, the participant thought it was difficult to tell the difference between warnings from different applications and commented that she "had to look first at iPad [to see] which warning I was getting [and] then check in mirrors—distracted. I hold a [commercial driver's license] I should be checking my mirrors first."
- The participant reported never receiving any false IMA alerts.

5.4.1.3 Perceived Safety Benefits

- The participant thought that the system warnings overall were effective at alerting to potential collisions, and also specifically for the BSW/LCW and IMA (other applications were not rated individually).
- The participant was neutral about whether or not the system increased driving safety overall, saying, "it's a useful tool but distracting."

5.4.1.4 Unintended Consequences

- To the question, "Did you find the warnings distracting?" the participant indicated disagreement. It is unclear grammatically what that response means but in light of the follow-up question—"Why?"—and other responses, the participant probably meant that they were distracting since they required looking at the screen to identify. The answer to the follow-up question was, "No audio warning—different sounds or voice telling me the warning would be great."
- The participant said monitoring or interpreting the information provided by the system was more distracting than using a car radio.

- The participant did not think that availability of the system will cause drivers to pay less attention to the driving environment because, “I think they will forget about it until a warning.”
- The participant did not notice any changes in her driving behavior as a result of driving with the system, saying “I’ve had a CDL for 20 years [with] no tickets or accidents, why change my driving behavior?”

5.4.1.5 Desirability

- The participant neither agreed nor disagreed with the statement, “Overall, I would like to have this CV System on my personal vehicle.” The same response was given for the BSW/LCW specifically. Overall satisfaction with the system was rated similarly, saying, “It’s useful but needs the audio to be helpful.” The IMA, on the other hand, was rated as desirable.
- The participant reported not receiving any EEBL alerts but rated desirability of it high, saying, “I would love that. Wish I had gotten the warning.”
- The participant reported not receiving any FCW alerts either, but rated desirability of it high, saying, “Would love to see how it worked.”
- The participant was not willing to pay for the system, either to have it in “their next new vehicle” or to have installed in “their existing vehicle.”

5.4.1.6 Privacy

- The participant was not willing to have the system installed if, when combined with other information, it allowed a business entity or a third-party organization to learn about her location and travel pattern. The participant was, however, willing to have the system if the entity learning about location and travel pattern was the government or “appropriate personnel to determine criminal behavior such as hacking.”

5.4.2 RSD Results

Results for the RSD users are organized similarly to that for the Integrated Truck, but with an additional section on the effect of experience on survey responses at the end. In this case, “experience” refers to the number of VMT or alerts received.

Twenty-four RSD users completed surveys, including 8 users of the RSD1 and 16 of the RSD2. RSD1 participants spent 17 months with the system, from October 2012 to February 2014. RSD2 participants spent 11 months with the system, from December 2012 to October 2013.

There is some concern that the majority of subjects reported not receiving warnings from the individual applications (Figure 31). Two of the RSD1 users reported not receiving alerts from any of the individual applications but still answered questions about the system overall. A few others reported not receiving alerts from a given application but still answered questions about it, including reporting changes in the frequency of alerts received. Consequently, some participants may have been unable to remember what type of alert they had received, or had simply misread the question.

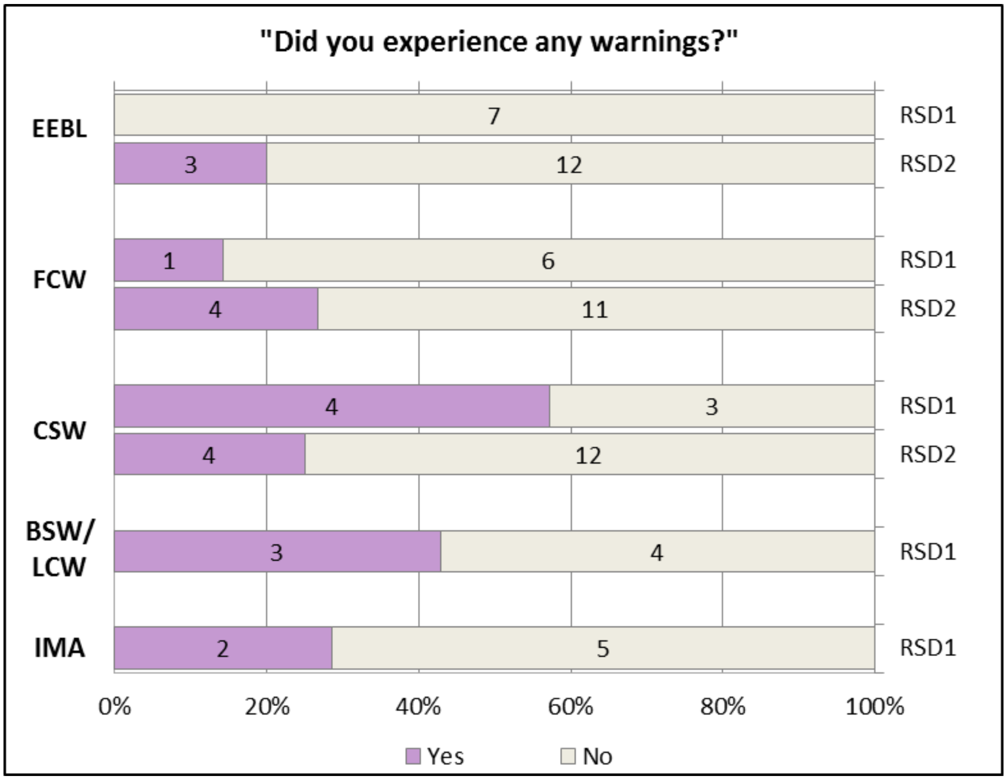


Figure 31. Perceived Experience with Application Alerts

5.4.2.1 Overall Impressions

When asked what they liked most about the RSD system, the most-frequent responses included advanced warning of potential collisions and the ease of use. The least-liked aspects were more diverse and included technical problems with the system crashing, interference with radio reception, and the bulky size of the RSD displays. Table 12 shows what each participant answered for the questions. The table is arranged so that a given driver's responses are side by side on the same row for comparison.

Table 12. Responses to What Each Participants Liked Most and Least

RSD	"What did you like most about the Connected Vehicle System?"	"What did you like least about the Connected Vehicle System?"
RSD1		"Placed too low in vehicle"
	"Curve warnings"	"When the system alarmed it was very startling"
	"The warning of vehicles too close"	"Didn't give an exact explanation of the warning going off"
	"The idea of if an accident occurred you'd be able to see exactly what happened"	"Felt like I was being watched at all times"
RSD2	"Never got an alert"	
		"Would not power up"

RSD	"What did you like most about the Connected Vehicle System?"	"What did you like least about the Connected Vehicle System?"
		"Too bulky—FM radio seems to not work as well"
	"Advance warning about what's ahead"	"Interfered when radio was on"
	"The screen was at right height for viewing!"	"Takes up too much space in cab!"
	"Very easy to use"	"It came loose from windshield easily"
	"Never had a chance to use it"	
	"Safety"	"Bulky"
	"I like that the system was easy to use and didn't take a lot of input to operate"	"Sometimes the system would shut down for no reason, but only once in a great while"
	"Easy to use"	"Crashed a lot"
	"The fact that the vehicles communicate with each other"	
	"Advance warnings"	"Interference with radio in the truck"
	"Easy to use"	"Suction cups didn't attach well"
	"Easy to use"	"Didn't stay on windshield"
	"Warnings"	"False warnings"
	"Advanced warning"	"Having to turn the system on every stop you shut the truck off at"

Satisfaction with the system overall was mostly neutral for both RSDs (Figure 32).

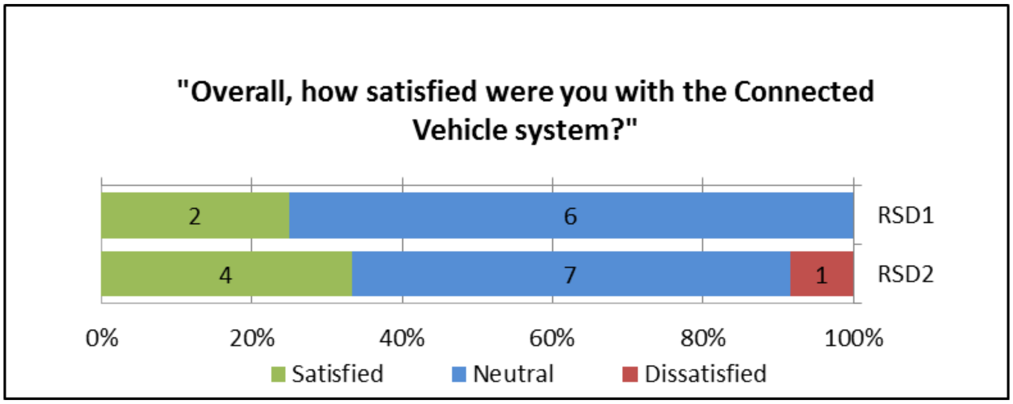


Figure 32. Overall Satisfaction with the System

5.4.2.2 Usability

Most participants were neutral about whether it was clear why the system issued warnings, both for the system overall and for the individual applications (Figure 33). This was particularly true for the EEBL and IMA applications, neither of which received positive responses. The application rated most clear was the CSW warning for the RSD1, which was rated clear by over half of respondents.

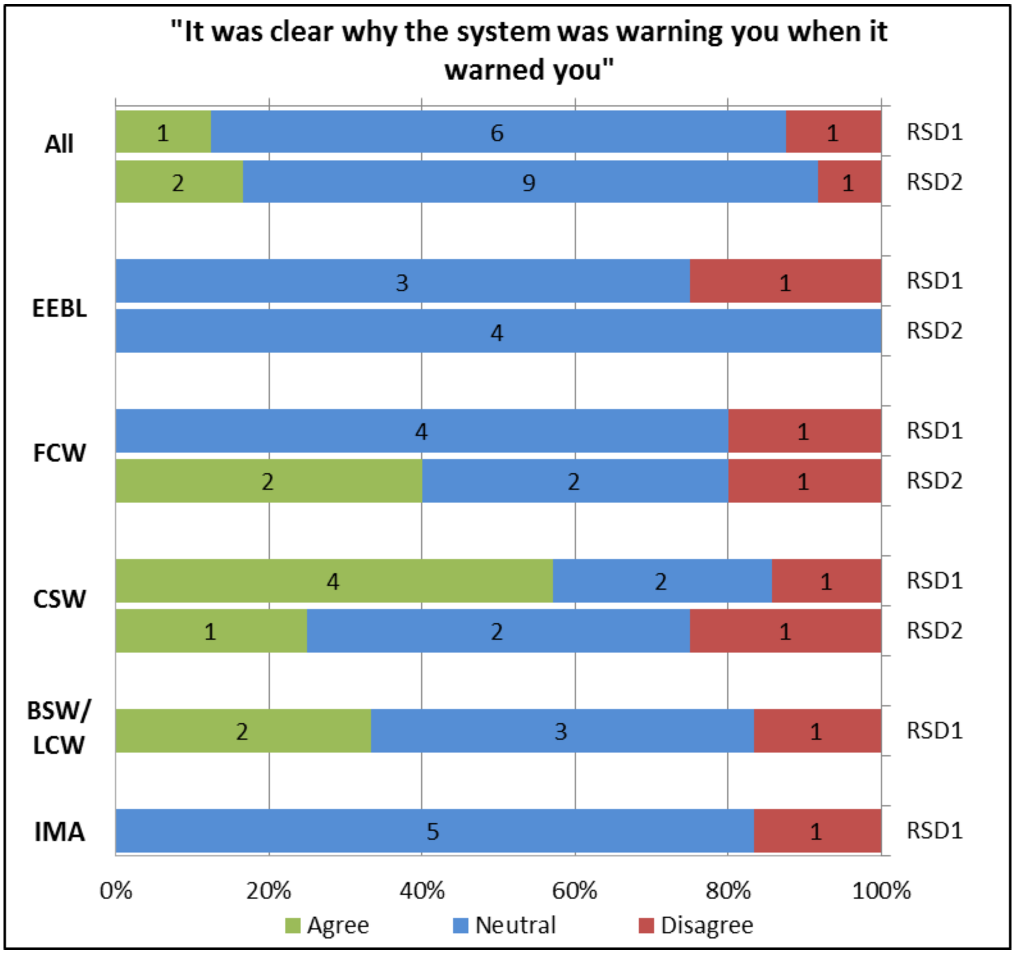


Figure 33. Clarity of Reason for Alerts

Participants were more neutral with the RSD1 about the ease of distinguishing between the warnings of the different applications (Figure 34). The RSD2, which included different audio tones for each application, received more mixed ratings.

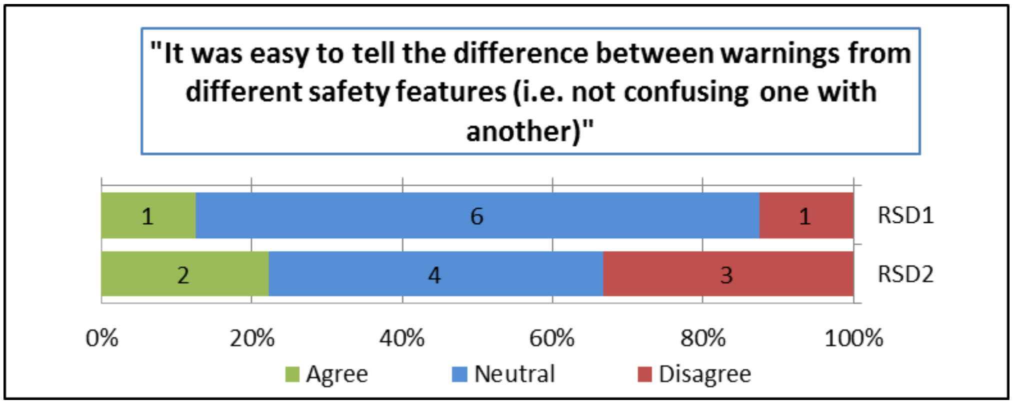


Figure 34. Ease of Distinguishing Between Application Alerts

Trust in the warnings varied between applications for RSD1 (Figure 35). Overall, the RSD1 and RSD2 received mostly neutral ratings. However, for RSD1 the responses were mostly or entirely neutral for the EEBL and FCW, mostly positive for the CSW, and more mixed for the BSW/LCW and IMA. For RSD2, the results were more positive for the EEBL, FCW, and CSW applications individually than for the system overall, with roughly half of responses being positive.

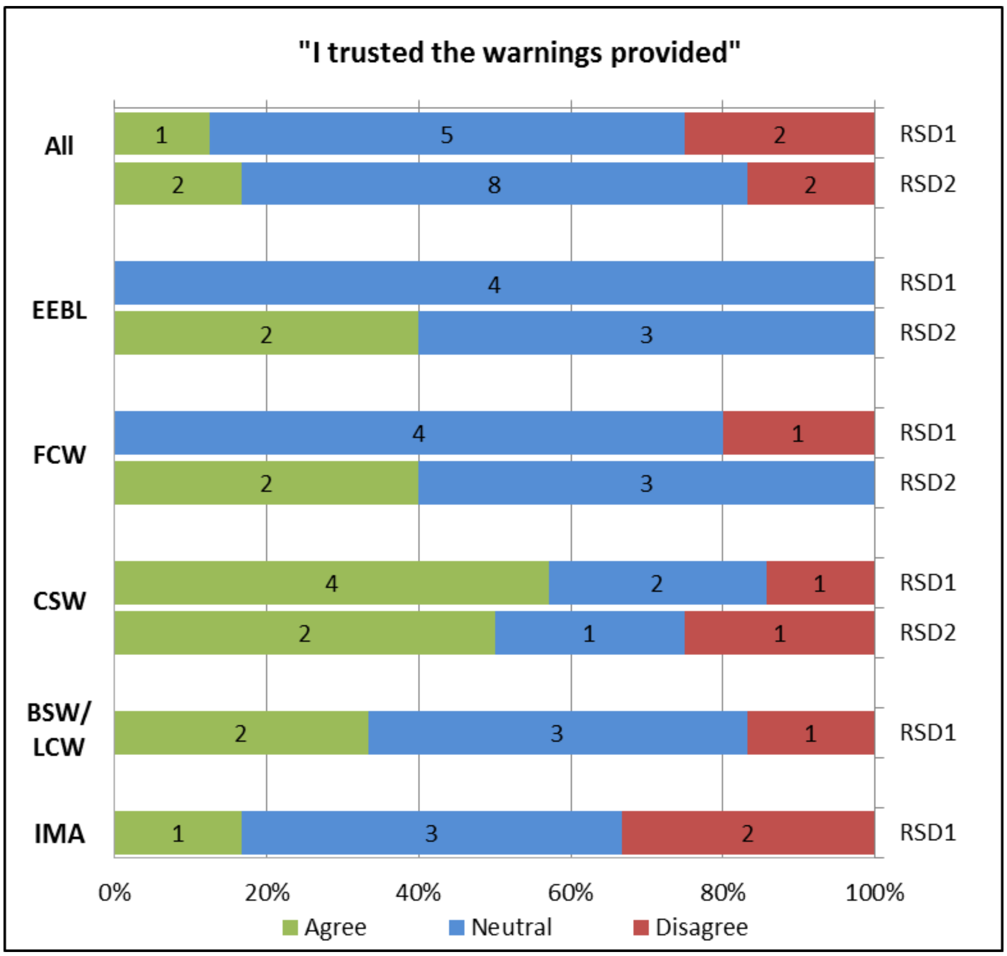


Figure 35. Trust in the Alerts Received

For RSD2, more participants said they never received incorrect alerts than did participants for RSD1 (Figure 36). For the CSW, no subjects reported receiving incorrect alerts. For the system overall, twothirds of participants were similarly positive. RSD1 participants were more mixed for the system overall, with the CSW again being rated most positively, followed by the BSW/LCW and IMA, and with the FCW receiving the most neutral responses.

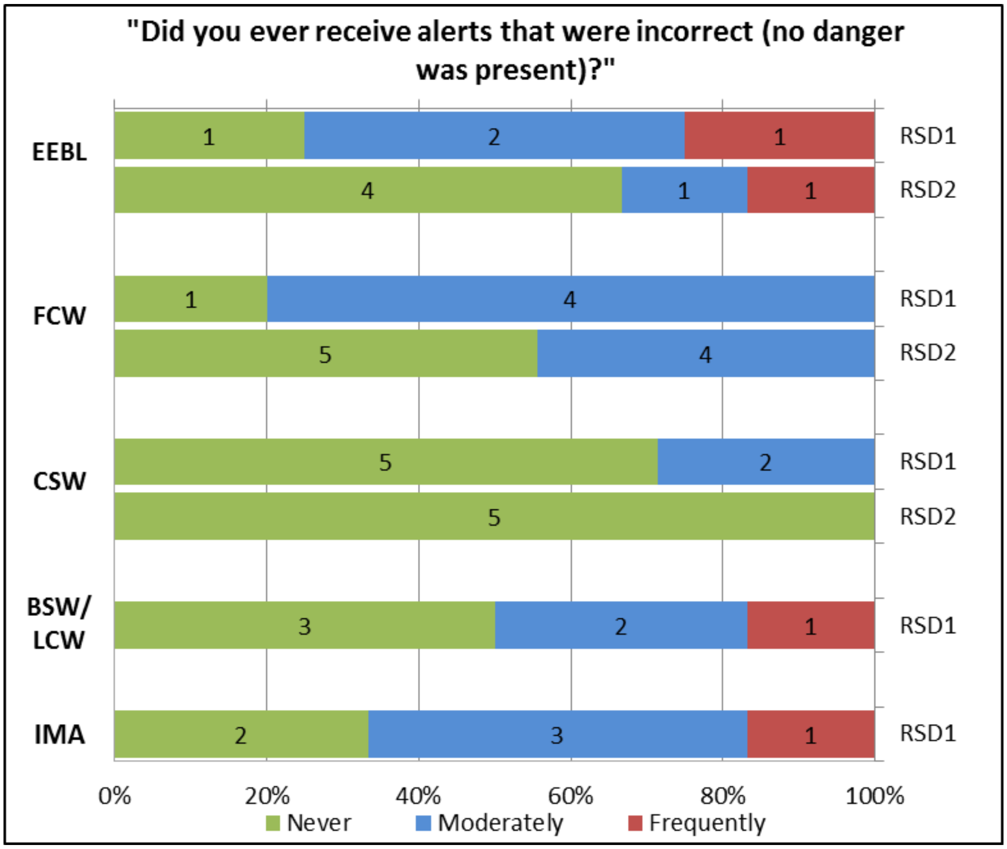


Figure 36. Perceived Rate of False Alerts

5.4.2.3 Perceived Safety Benefits

The effectiveness of the warnings at alerting participants to potential collisions was mostly neutral overall (Figure 37). With RSD1, the EEBL and FCW were rated lowest, the CSW highest, and the BSW/LCW and IMA somewhere in between. For RSD2, the EEBL was rated negatively, and the FCW and CSW received more mixed responses.

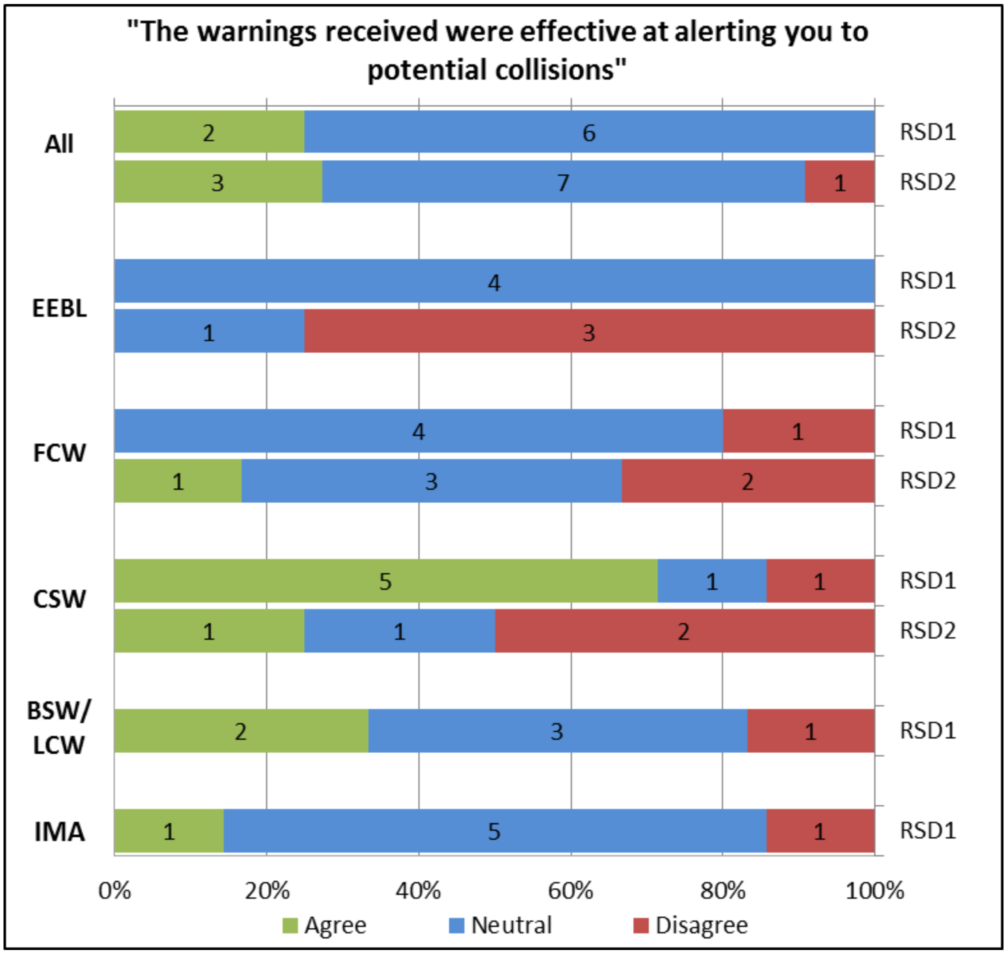


Figure 37. Perceived Effectiveness of System Alerts

Not surprisingly, the effectiveness of the system at alerting to potential collisions was similar to the rated increase in driving safety caused by the system overall: mixed but predominantly neutral (Figure 38).

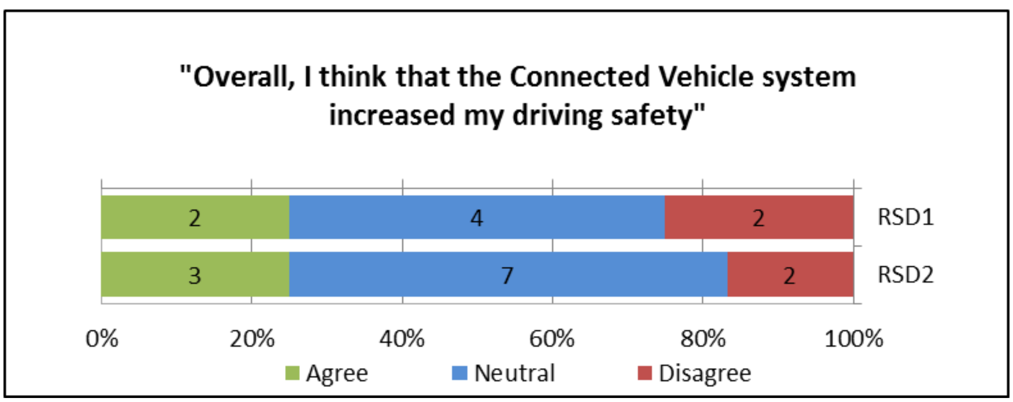


Figure 38. Perceived Safety Benefit of the System

5.4.2.4 Unintended Consequences

Five out of 8 (63%) RSD1 users thought the system warnings were not distracting, whereas an even stronger majority (9 out of 12, or 75%) was neutral about the RSD2 (Figure 39).

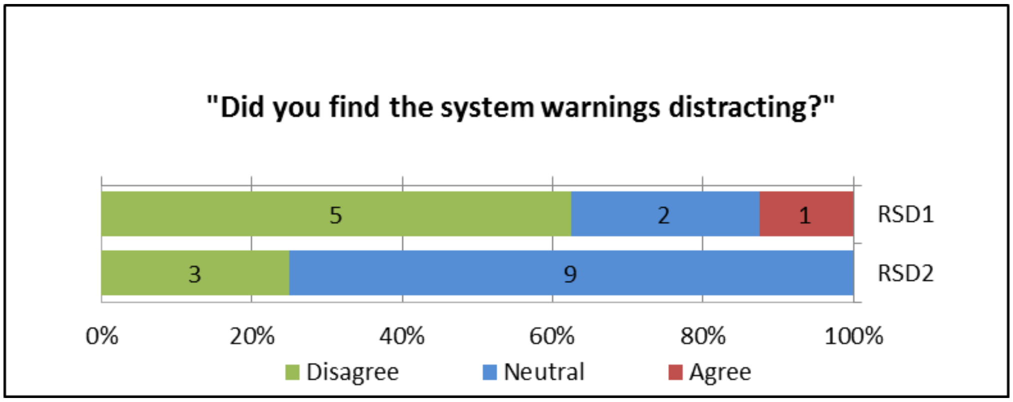


Figure 39. Perceived Distraction Caused by the Alerts

When the risk of distraction was compared to that of using a car radio, both RSD1 and RSD2 users gave similarly mixed results with slightly more neutral responses than positive or negative (Figure 40).

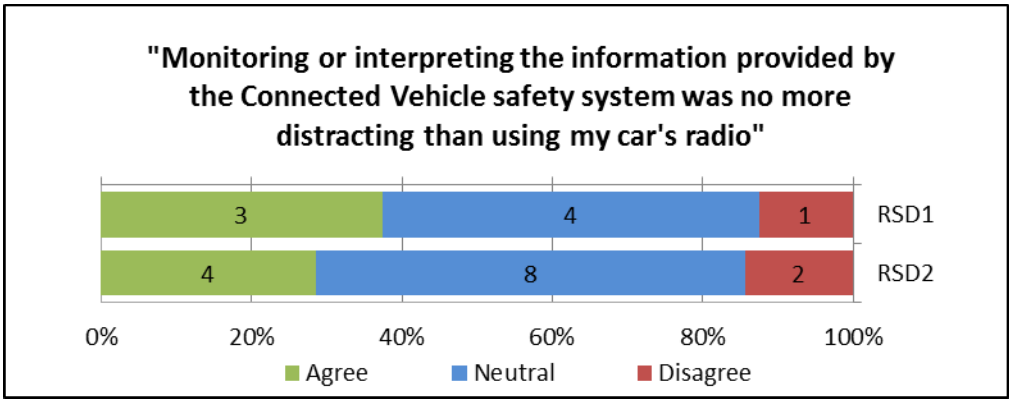


Figure 40. Perceived Distraction Compared to Using Car Radio

Distinct from distraction is the risk of overreliance, in which drivers learn to pay less attention to the driving environment due to the availability of the warning systems (Figure 41). The majority of RSD1 users (6 out of 8, or 75%) were neutral, with a few seeing no risk. For RSD2, though, roughly as many thought there was a risk of overreliance as were neutral, and a smaller number saw no risk of overreliance.

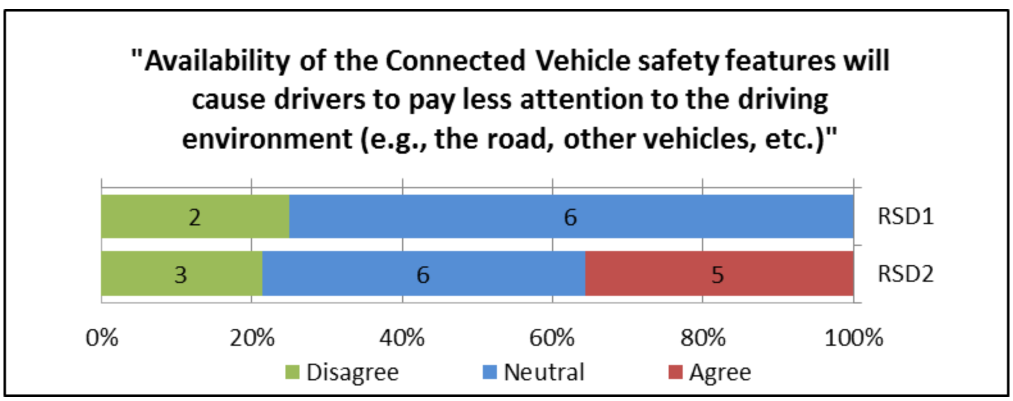


Figure 41. Perceived Risk of Overreliance

5.4.2.5 Desirability

Not surprisingly, given the previous results, desirability for the system overall was mixed but mostly neutral, both for the RSD1 and RSD2 systems (Figure 42). For RSD1, only the EEBL differed from the overall mixed rating, with half of respondents being neutral and half not wanting the EEBL at all. For RSD2, the standout was the FCW, which was more strongly neutral than the other applications.

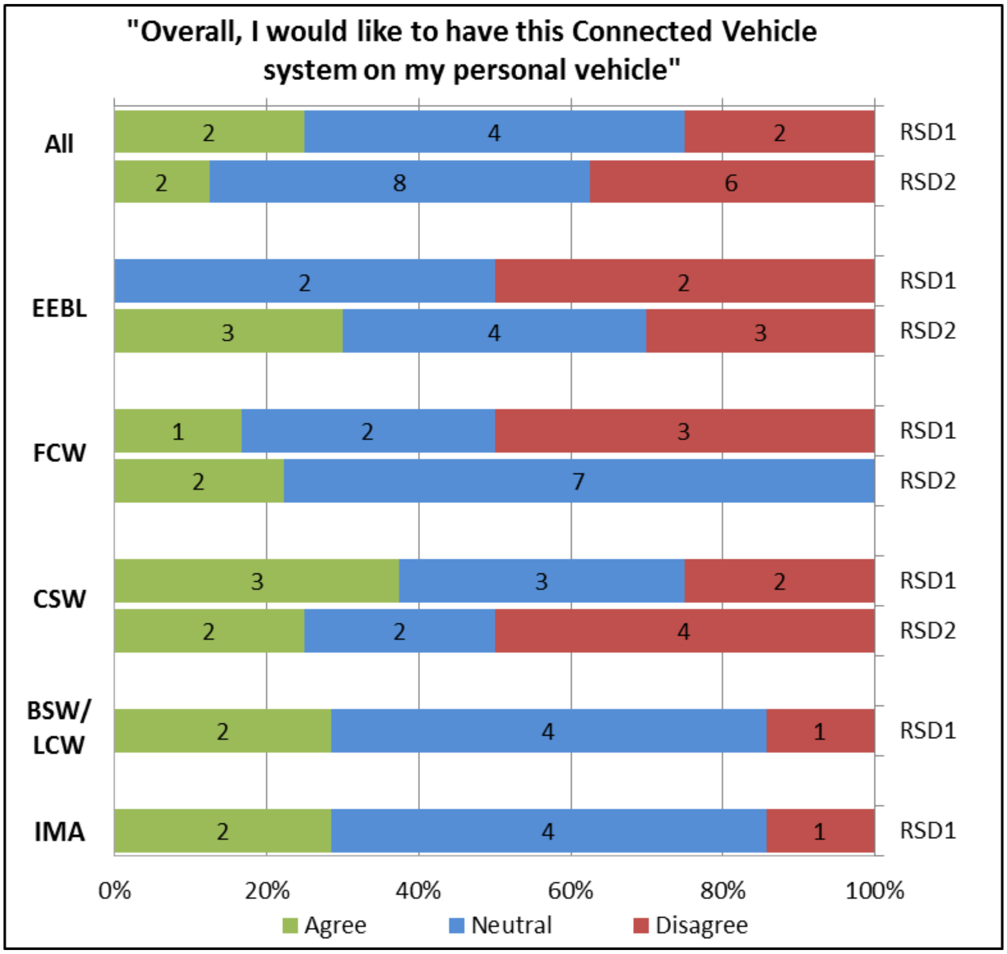


Figure 42. Rated Desirability of the Systems

Desirability can be loosely quantified in terms of a dollar amount; in this case, the cost of installation in a new or existing vehicle (Figure 43). There was no statistical difference between prices for new and existing vehicles for RSD2 users, RSD1 users, or for both combined *(p > .05 for all tests)*. For installation in an existing vehicle, RSD2 users set the price at an average of $333 (SD: $197) and RSD1 users $150 (SD: $238). This difference was not significant *(p > .05 for all tests)*. For the cost in a new vehicle, however, there was a trend towards statistical significance: RSD2 users set the price at an average of $533 (SD: $377), compared to RSD1 users who set the price at $150 (SD: $206) *(between-subjects t-test*, t = -2.1, df = 12, p = .06, two-tailed).

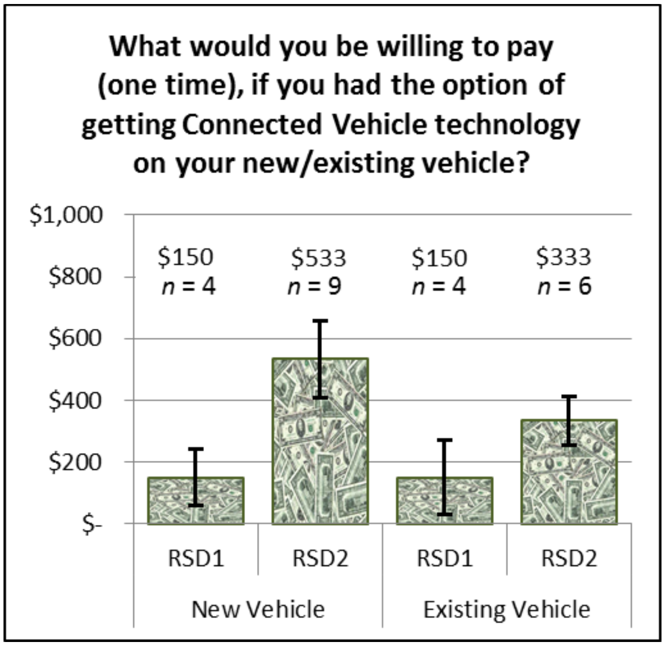


Figure 43. Acceptable Price for System

The willingness of participants to have the warning system if they had to periodically visit another location for updates can give some indication of desirability since it can be seen as a sort of cost for having the system. When asked about their willingness to have the system under that condition, 5 out of 8 RSD1 users were neutral. Out of the RSD2 users, 7 (44%) were neutral and 8 (50%) were not willing to have the system (Figure 44).

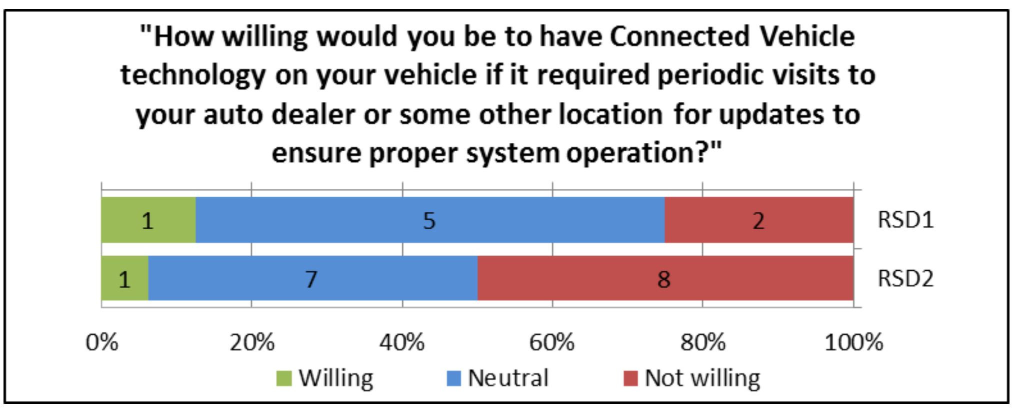


Figure 44. Willingness to Bring Vehicle in for Updates

5.4.2.6 Privacy

Opinions of data privacy and security were evaluated by asking participants how willing they would be to have a V2V-based warning system in their vehicle if certain other parties were able to learn about their vehicle's driving behavior and pattern (Figure 45). Among business entities, the government, and a third party, over half of respondents were not willing to have the system under those conditions for RSD1 and RSD2. This was true even in the special case of "appropriate personnel to determine criminal behavior such as hacking."

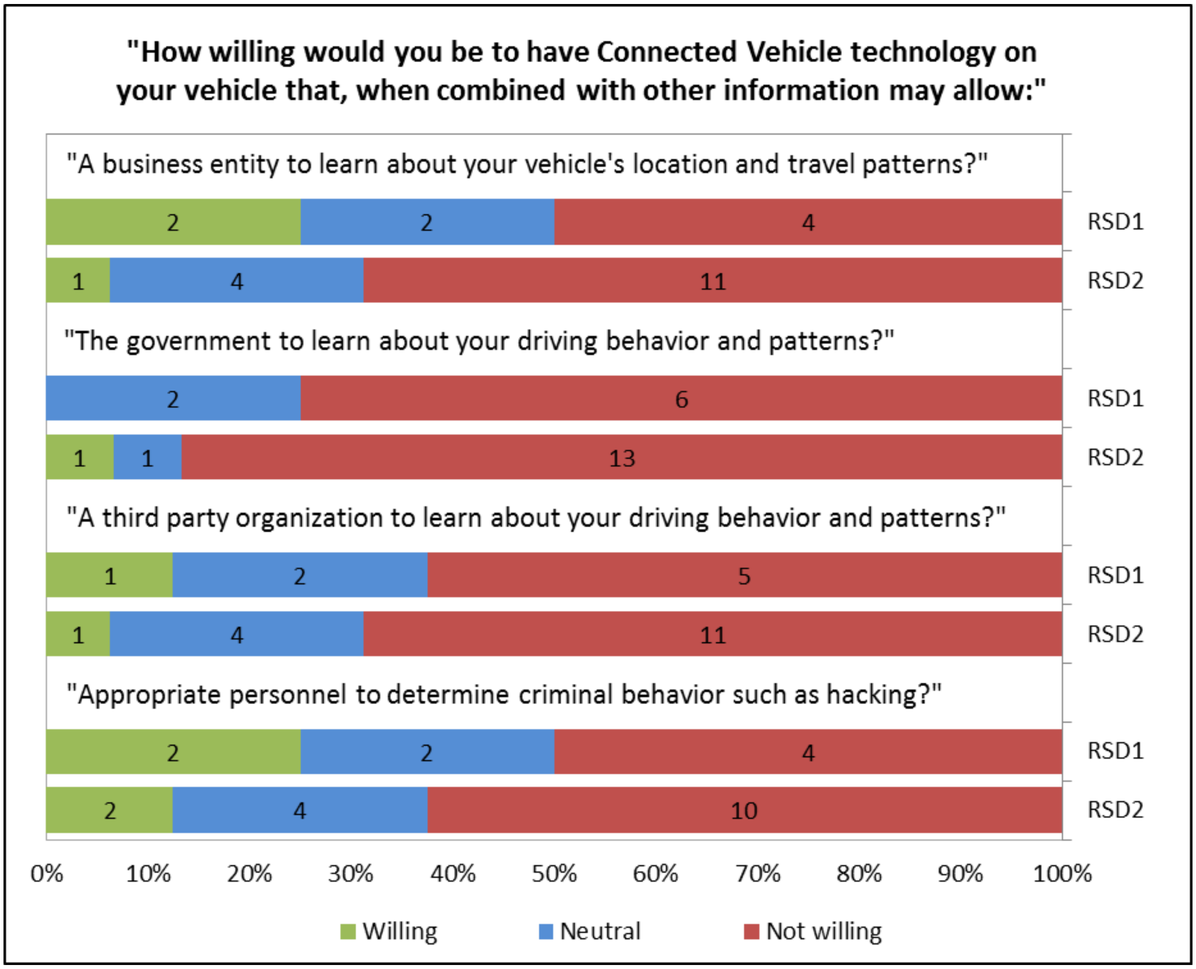


Figure 45. Willingness to Use System Given Privacy Concerns with Different Entities

5.4.2.7 Effect of Experience

Alert numbers and VMT were only available for the eight users of the RSD1. Consequently, all analyses in this subsection apply only to RSD1.

There were no significant correlations with VMT and few with the total number of alerts received. Instead, most meaningful correlations were with the number of alerts per VMT (here formatted as the number of alerts per 1,000 VMT due to the very low number of alerts received). There was a trend for the overall effectiveness of the warning system to be higher the more alerts a participant received (*Spearman's* $r_s = .67$, $n = 8$, $p = .07$) (Figure 46).

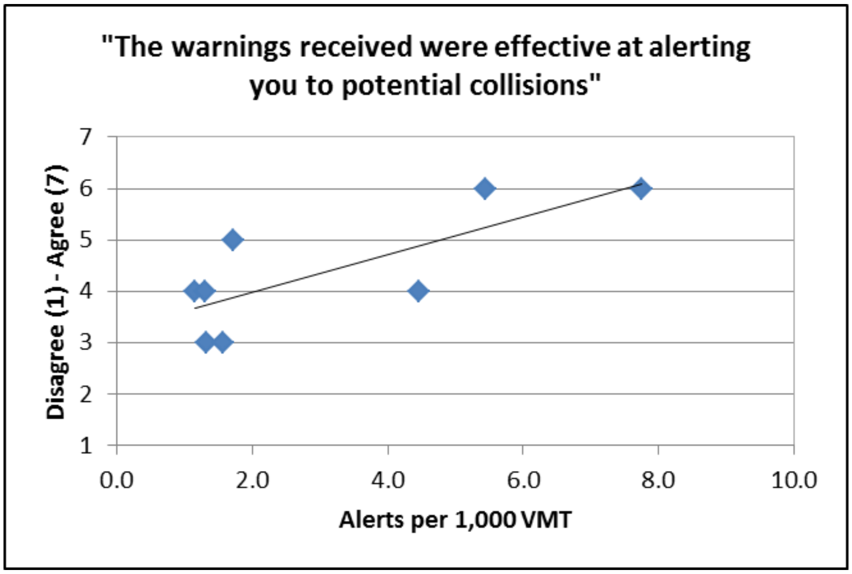


Figure 46. Rated Effectiveness as Function of Alerts per 1,000 VMT

Not surprisingly, the perceived increase in driving safety conferred by the warning system also increased with the number of alerts received per VMT (r_s = .86, n = 8, p = .006) (Figure 47).

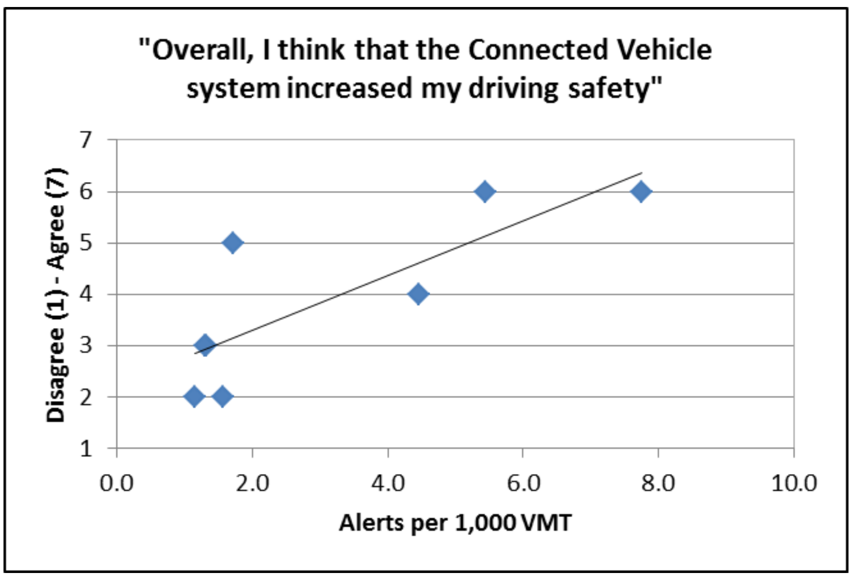


Figure 47. Rated Safety Benefits as Function of Alerts per 1,000 VMT

Agreement that using the system was no more distracting than using the car radio also increased with the number of alerts received per VMT (r_s = .74, n = 8, p = .04) (Figure 48). Responses to this question were also correlated with the number of CSW alerts received (r_s = .85, n = 8, p = .007) and there was a weak trend for a correlation with the number of IMA alerts received (r_s = .64, n = 8, p = .09).

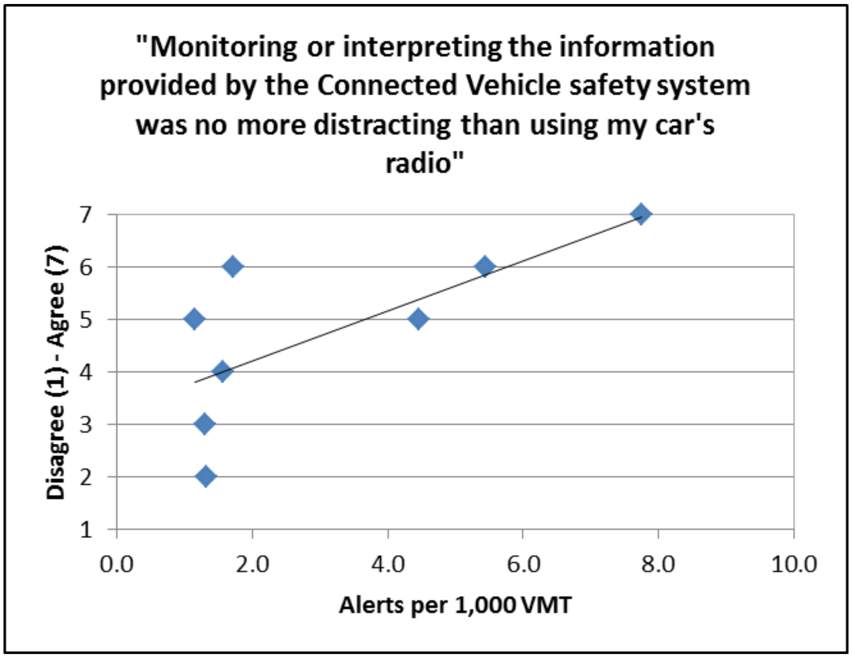


Figure 48. Rated Distraction Relative to Car Radio as Function of Alerts per 1,000 VMT

Lastly, there was a highly significant positive correlation between the number of alerts per VMT received and the willingness to have the system if it required periodic visits to a shop for updates ($r_s = .95$, $n = 8$, $p < .01$) (Figure 49). Responses to this question were also significantly positively correlated with the total number of alerts received ($r_s = .73$, $n = 8$, $p = .04$) and the number of IMA alerts received ($r_s = .77$, $n = 8$, $p = .03$).

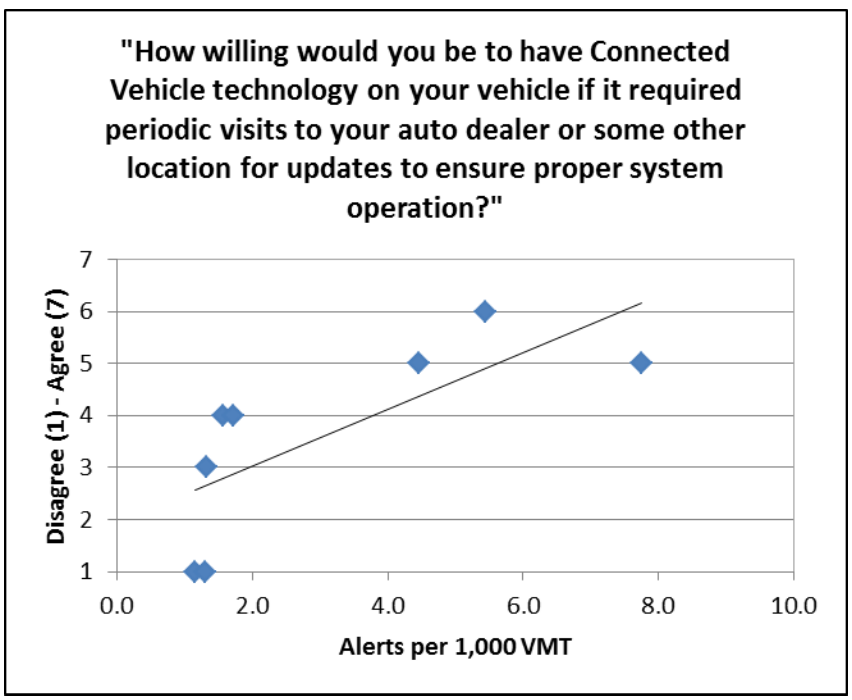


Figure 49. Rated Willingness to Visit Dealer to Have System as Function of Alerts per 1,000 VMT

6 Conclusions

Overall, the SPMD demonstrated that V2V and V2I technology can be deployed in a real-world driving environment. The safety applications issued warnings in the safety critical driving scenarios that they were designed to address. The SPMD was also crucial in revealing areas for improving the performance of the DSRC technology and the prototype safety applications which could not have been identified in controlled testing environments. It should be noted here that there were no crashes in this study.

This section presents the key findings from the SPMD evaluation. Findings are separated into three main categories: system capability, unintended consequences, and driver acceptance.

6.1 System Capability

The SPMD demonstrated the feasibility of V2V and V2I safety applications, but also revealed the areas where the applications have room for improvement.

The most critical area for improvement in the prototype safety applications is properly determining the relative location of RVs with lane-level accuracy. This impacted the FCW safety application, since this application attempts to issue warnings only for RVs in the same lane as the HV. Relative position accuracy is impacted by many factors including GPS accuracy, the timeliness and accuracy of the messages received from the RV, road geometry, and the data processing software of the application.

Two areas for future improvement include the suppression of false alerts issued by the RSD1s at overpasses and tailoring the IMA application so that warnings are not issued when the driver is not intending to proceed into the intersection. An example of this is when a driver is creeping forward at an intersection but does not immediately intend to proceed. Additional research on driver behavior at intersections is needed to properly improve the IMA application in timely crash-imminent alerts and false-alert suppression.

Specific findings for each application are discussed below:

6.1.1 FCW

- The percentage values of FCW alerts issued for in-path RVs were 12 percent and 43 percent for RSD1s and RSD2s respectively, and 32 percent for the integrated truck #15501. The remaining alerts were false.
- The in-path alert percentage of FCW alerts issued for stopped RVs was lower than for moving RVs for both RSD1s and integrated truck #15501. Due to the small number of alerts issued by the RSD2s, this data was not included in the analysis.
- The majority of in-path alerts were issued during LVD scenarios for both RSD1s and integrated truck #15501. Limited numerical data collected from the RSD2s precluded this information from being obtained.
- The percentages of in-path alerts issued on curves was greater when the HV was located at curve entry and in the curve compared to being located on the straight road approaching the curve. The percentages of alerts issued when the HV was approaching on a straight road were approximately the same for both RSD1s and integrated truck #15501. There were no alerts issued on curves by the RSD2s.
- Alert performance by RV range showed similar results for both RSD1s and the integrated truck #15501. Alerts issued for RVs between 30 and 60 m away had the highest in-path percentages for both the RSD1s and integrated truck #15501. Limited numerical data collected from the RSD2s precluded this information from being obtained.

- In regard to alert performance by RV device type, similar trends were observed between the RSD1s and the integrated truck #15501. There was a large disparity (78%compared to 9%) in percentages of RSD1 in-path alerts triggered by RSD1 equipped trucks compared to in-path alerts triggered by ASDs and VADs combined. There was also a large difference (94% compared to 25%) in percentages of integrated truck #15501 in-path alerts triggered by remote integrated trucks compared to in-path alerts triggered by ASDs and VADs combined. Limited numerical data collected from the RSD2s precluded this information from being obtained.
- There was one observed instance of missed FCW alert in the RSD1 dataset.

6.1.2 IMA

- The percentage values of IMA alerts that occurred at intersections were 37 percent and 63 percent for the RSD1s and integrated truck #15501 respectively.
- The majority of the false alerts (50% of all IMA alerts) issued by the RSD1s occurred at an overpass. These false alerts represent opportunities for software refinement to account for elevation in the GPS data. The percentage of false alerts issued at an overpass by the integrated truck #15501 was small (7%). This could be attributed to the UMTRI drivers driving in areas where there were no overpasses. It could also be that the integrated truck #15501 system accounts for elevation in the GPS data.
- The majority of the RSD1 and integrated truck #15501 IMA alerts issued at intersections were triggered by VADs and ASDs.
- One potential missed IMA stopped event was identified in the RSD1 dataset.
- There were no observed instances of missed IMA moving alerts in the SPMD.

6.1.3 BSW/LCW

- Eighty-eight percent of BSW alerts issued by the RSD1s were for RVs in the adjacent lane. None of the events involved a steering response from the driver. It should be noted here that the RSD1s were equipped with BSW only (cautionary alert with no audio).
- Seventy-one percent of BSW/LCW alerts issued by the integrated truck #15501 were for vehicles in the adjacent lane. None of the events involved a steering response from the driver.
- There was one observed missed LCW alert in the integrated truck #15501 dataset.

6.1.4 EEBL

- The majority of the alerts (73%) issued by the RSD1s were for in-path and adjacent lane RVs. Two of the eleven events involved an obstructing LV.
- All 5 alerts issued by the integrated truck #15501 were for in-path RVs. One of the 5 events involved an obstructing LV.
- There was no EEBL data collected from the RSD2s.

6.1.5 CSW

- All CSW alerts were issued by RSD1s. The majority of the alerts were issued at the entry points to equipped curves located on Plymouth Road (71%) and Bonisteel Boulevard (65%). The percentage values of alerts issued in the equipped curves located on Plymouth Road and Bonisteel Boulevard were 12 percent and 35 percent respectively. The percentage of CSW alerts issued at curve entry and in the equipped curve on both Plymouth Road and Bonisteel Boulevard combined is 91 percent.

- All CSW alerts were issued at or above the threshold speeds. None of the CSW alert events involved the driver braking when the alert was issued.
- There were two observed instances of missed CSW alerts.
- There was no CSW data collected from the RSD2s.

6.2 Unintended Consequences

Unintended consequences of FCW and IMA safety applications have been analyzed and discussed. Drivers' reactions to 37 crash-imminent alerts issued during potential hazard scenarios by the V2V safety applications were observed. Comparison of paired treatment alert and control event braking response and acceleration levels did not reveal any unintended consequences in the FCW and IMA conflicts, and the drivers did not appear startled or annoyed by the alerts during these conflicts. In addition, the drivers were generally attentive when they received the alerts.

6.3 Driver Acceptance

Key driver acceptance findings for the integrated truck and RSDs are summarized below.

6.3.1 Integrated Truck

- Feedback only received from a single participant, not generalizable to general population.
- Participant liked the IMA and BSW applications, but thought that the benefit of the system was counteracted by the distraction caused by having to look down at the display to identify the warning type, since that could not be identified by audio tone alone.
- Participant was neutral about having the system and was not willing to pay any money for it.

6.3.2 Retrofit Safety Devices

- Overall rated satisfaction was largely neutral, with more than half of participants giving a neutral rating (75% for the RSD1).
- Participants rated their understanding of why alerts were issued mostly neutral (75% gave a neutral rating for the system overall). Roughly the same results were given for individual systems, with the exception of the CSW for the RSD1, for which over half of participants gave a positive rating indicating understanding.
- The effectiveness of the system to alert the participants to potential collisions was given an overall neutral rating, with over 70 percent of both RSD1 and RSD2 users giving neutral responses. For RSD1, the EEBL and the FCW received the worst ratings, and the CSW the best. For RSD2, the EEBL also received low ratings and the CSW and FCW more mixed responses. The perceived safety benefits conferred by the overall system were also neutral for both RSDs.
- Over 60 percent of RSD1 users thought the warnings were not distracting and 75 percent of RSD2 users were neutral, indicating that distraction was not seen as a big concern.
- RSD1 participants were also mostly neutral when it came to agreeing with a statement stating that the system will lead to overreliance (for RSD2 the responses were more mixed).
- Desire for the system was mixed and a majority was neutral for the systems overall and for individual applications. No RSD1 users reported wanting to have the EEBL.

- More than half of participants were not willing to have the system if it enabled the government, a business entity, or a third party to learn about their driving behavior and patterns. This was true even for "appropriate personnel" to prevent criminal behavior such as hacking.
- The more alerts participants received per VMT, the higher they rated warning effectiveness and perceived safety benefits, the more they agreed that the system was no more distracting than a car radio, and the more willing they would be to have the system if it required periodic trips to the shop for updates.

Especially with regard to survey questions asking participants to rate their agreement with a statement, the large number of neutral responses may indicate that participants were unsure how they felt, possibly due to a lack of experience with the alerts given how few there were overall (and due to alerts only occurring with the subset of interactions that occurred with other equipped vehicles). This would explain why responses tended to be more favorable with increasing rates of alerts per VMT, at least with regard to perceived effectiveness and safety benefits.

7 References

[1] Nodine, E., Stevens, S., Najm, W. G., Jackson, C., & Lam, A. (in press). *Independent evaluation of light-vehicle safety applications based on vehicle-to-vehicle communications used in the Safety Pilot Model Deployment* (Interim Report No. DOT-VNTSC-NHTSA-14-02), Washington, DC: National Highway Traffic Safety Administration,

[2] Nodine, E., Stevens, S., Najm, W. G., Jackson, C., & Lam, A. (2015, February). *Independent evaluation of the transit retrofit package safety applications* (Report No. FHWA-JPO-14-175). Washington, DC: Federal Transit Agency, Intelligent Transportation Systems Joint Program Office, & Federal Highway Administration. Available at http://ntl.bts.gov/lib/54000/54800/54839/FHWA-JPO-14-175_v1.pdf

Appendix A: Post-Drive Questionnaire – RSD1

Participant #___________

Date _____________

Impressions of the Connected Vehicle System

1. What did you like *most* about the Connected Vehicle system?

____

____

2. What did you like *least* about the Connected Vehicle system?

____

____

3. Thinking about the warnings you received when using the system, please rate the following:

   a. It was clear *why* the system was warning you when it warned you

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Additional comments:

____

   b. I trusted the warnings provided

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

1

c. The warnings received were effective at alerting you to potential collisions

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

d. It was easy to tell the difference between warnings from different safety features (i.e. not confusing one warning with another)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

i. What warnings did you find confusing?

____

4. When were the warnings from the Connected Vehicle system *most* helpful?

____

____

5. When were the warnings from the Connected Vehicle system *least* helpful?

____

____

6. Overall, I think that the Connected Vehicle system increased my driving safety.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

2

7. Did you find the system warnings distracting?

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

8. Monitoring or interpreting the information provided by the Connected Vehicle safety system was no more distracting than using my car's radio

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

9. Availability of the Connected Vehicle safety features will cause drivers to pay less attention to the driving environment (e.g., the road, other vehicles, etc.)

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

10. Did you notice any changes in your driving behavior as a result of driving with the Connected Vehicle system? Yes____ No____

Why or why not?

____

3

a. If yes, what behaviors do you think changed as a result of having the technology in your vehicle? [Circle all that apply]

i. I became more aware of driving situations that could cause a warning

ii. I was more cautious after receiving a warning

iii. I started to pay less attention because I relied on the warning

iv. I drove differently to prevent the system from warning me

v. Others, please fill in below

____

b. Additional comments?

____

11. What would you be willing to pay (one time), if you had the option of getting Connected Vehicle technology:

a. On your next *new vehicle*? $________________

b. If it could be added to *your existing vehicle*? $________________

12. Overall, I would like to have this Connected Vehicle system on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

13. Overall, how satisfied were you with the Connected Vehicle system?

1	2	3	4	5	6	7
Very Dissatisfied						Very Satisfied

Why?

____

4

Integrated Vehicles

Emergency Electronic Brake Lights (EEBL)

EEBL tells you if there is a stopped vehicle or one slowing down quickly, either directly in front of you or some distance ahead. This can be particularly helpful when you can't see in front of you, such as when other vehicles are blocking your view or when the weather is bad.

Did you experience any EEBL warnings? (circle one) Yes No

If you circled "yes," continue with the questions below. If you circled "no," please skip to the next section.

1. What specifically did you like *most* about the EEBL system?

____

____

2. What specifically did you like *least* about the EEBL system?

____

____

3. Thinking about the EEBL warnings you received, please rate the following:

    a. It was clear why the EEBL issued a warning when it did – you could tell that there was another vehicle in your path ahead that was stopped or that was braking hard

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Additional comments:

____

    b. I trusted the EEBL warnings

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

5

c. How effective was EEBL at alerting you to the presence of a vehicle ahead that is braking hard?

1	2	3	4	5	6	7
Not at all Effective						Completely Effective

Why?

____

4. Did you ever receive EEBL alerts that were incorrect (no danger was present)?

1	2	3	4	5	6	7
Never						Frequently

   a. If you received incorrect EEBL alerts:
      i. How often did you receive an unnecessary EEBL alert?
         a. Everyday
         b. Few times per week
         c. Once a week
         d. Few times per month
         e. Once a month
         f. Very rarely
         g. Never
      ii. Did the number of alerts change over the course of your evaluation (increase or decrease)?

      ____

      iii. Could you tell why the EEBL seemed to be alerting you?

      ____

5. What, if anything, would you change about the EEBL safety feature, and why?

____

____

6. I would like to have EEBL on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

6

Please indicate your overall acceptance rating of the Emergency Electronic Brake Light warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The **Emergency Electronic Brake Light warnings** were:

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

7

Forward Collision Warning (FCW)

FCW helps to warn drivers to avoid an impending rear-end collision with a lead vehicle ahead in traffic, in the same lane and direction of travel.

Did you experience any FCW warnings? (circle one) Yes No

If you circled "yes," continue with the questions below. If you circled "no," please skip to the next section.

1. What specifically did you like *most* about the FCW system?

____

____

2. What specifically did you like *least* about the FCW system?

____

____

3. Thinking about the FCW warnings you received, please rate the following:

   a. It was clear why the FCW issued a warning when it did – you could tell that there was another vehicle in your path ahead that was stopped or moving more slowly than yours

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Additional comments:

____

   b. I trusted the FCW warnings

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

8

c. How effective was FCW at alerting you to the presence of a vehicle ahead that is braking hard

1	2	3	4	5	6	7
Not at all Effective						Completely Effective

Why?

____

4. Did you ever receive FCW alerts that were incorrect (no danger was present)?

1	2	3	4	5	6	7
Never						Frequently

a. If you received incorrect FCW alerts:
    i. How often did you receive an unnecessary FCW alert?
        a. Everyday
        b. Few times per week
        c. Once a week
        d. Few times per month
        e. Once a month
        f. Very rarely
        g. Never
    ii. Did the number of alerts change over the course of your evaluation (increase or decrease)?

    ____

    iii. Could you tell why the FCW seemed to be alerting you?

    ____

5. What, if anything, would you change about the FCW safety feature, and why?

____

____

6. I would like to have FCW on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

9

Please indicate your overall acceptance rating of the Forward Collision warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The **Forward Collision warnings** were:

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

10

Curve Speed Warning (CSW)

CSW helps to warn drivers that they are traveling too fast to safely take an upcoming curve.

Did you experience any CSW warnings? (circle one) Yes No

If you circled "yes," continue with the questions below. If you circled "no," please skip to the next section.

1. What specifically did you like *most* about the CSW system?

____

____

2. What specifically did you like *least* about the CSW system?

____

____

3. Thinking about the CSW warnings you received, please rate the following:

   a. It was clear why the CSW issued a warning when it did

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Additional comments:

____

   b. I trusted the CSW warnings

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

11

c. How effective was CSW at alerting you to the presence of a sharp curve ahead?

1	2	3	4	5	6	7
Not at all Effective						Completely Effective

Why?

____

4. Did you ever receive CSW alerts that were incorrect (no curve was present)?

1	2	3	4	5	6	7
Never						Frequently

a. If you received incorrect CSW alerts:

i How often did you receive an unnecessary CSW alert?

a. Everyday
b. Few times per week
c. Once a week
d. Few times per month
e. Once a month
f. Very rarely
g. Never

ii. Did the number of alerts change over the course of your evaluation (increase or decrease)?

____

iii. Could you tell why the CSW seemed to be alerting you?

____

5. What, if anything, would you change about the CSW safety feature, and why?

____

6. I would like to have CSW on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

12

Please indicate your overall acceptance rating of the Curve Speed warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The **Curve Speed warnings** were:

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

13

Blind Spot Warning (BSW)

BSW lets drivers know that a vehicle in an adjacent lane is positioned in a blind-spot zone.

Did you experience any BSW warnings? (circle one) Yes No

If you circled "yes," continue with the questions below. If you circled "no," please skip to the next section.

1. What specifically did you like *most* about the BSW system?

____

____

2. What specifically did you like *least* about the BSW system?

____

____

3. Thinking about the BSW warnings you received, please rate the following:

   a. It was clear why the BSW indicator came on when it did – you could tell that there was another vehicle in your blind spot

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Additional comments:

____

   b. I trusted the BSW indicators

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

14

c. How effective was BSW indicator at alerting you to the presence of a vehicle in your blind spot?

1	2	3	4	5	6	7
Not at all Effective						Completely Effective

Why?

____

4. Did the BSW indicator ever provide information that was incorrect (no vehicle present in your blind spot)?

1	2	3	4	5	6	7
Never						Frequently

   a. If you received incorrect BSW alerts:
      i. How often did you receive incorrect information from the BSW?
         a. Everyday
         b. Few times per week
         c. Once a week
         d. Few times per month
         e. Once a month
         f. Very rarely
         g. Never
      ii. Did the number of alerts change over the course of your evaluation (increase or decrease)?

      ____

      iii. Could you tell why the BSW seemed to be incorrectly alerting you?

      ____

5. What, if anything, would you change about the BSW safety feature, and why?

____

6. I would like to have BSW on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

15

Please indicate your overall acceptance rating of the Blind Spot Warning (BSW)

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The **Blind Spot Warnings (BSW)** were:

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

16

Intersection Movement Assist (IMA)

IMA warns drivers when it is not safe to enter an intersection due to a high probability of crashing with other vehicles also approaching the intersection, and helps drivers avoid or mitigate intersection crashes.

Did you experience any IMA warnings? (circle one)   Yes   No

If you circled "yes," continue with the questions below. If you circled "no," please skip to the next section.

1. What specifically did you like *most* about the IMA system?

____

____

2. What specifically did you like *least* about the IMA system?

____

____

3. Thinking about the IMA warnings you received, please rate the following:

   a. It was clear why the IMA issued a warning when it did – you could see another vehicle in the intersection that could have posed a danger to your vehicle

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Additional comments:

____

   b. I trusted the IMA warnings

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

Why?

____

17

c. How effective was IMA at alerting you to the presence of the vehicle in that may pose danger when you entered an intersection

1	2	3	4	5	6	7
Not at all Effective						Completely Effective

Why?

____

4. Did you ever receive IMA alerts that were incorrect (no vehicle posing a threat when entering an intersection)?

1	2	3	4	5	6	7
Never						Frequently

a. If you received incorrect IMA alerts:
    i. How often did you receive an unnecessary IMA alert?
        a. Everyday
        b. Few times per week
        c. Once a week
        d. Few times per month
        e. Once a month
        f. Very rarely
        g. Never
    ii. Did the number of alerts change over the course of your evaluation (increase or decrease)?

    ____

    iii. Could you tell why the IMA seemed to be alerting you?

    ____

5. What, if anything, would you change about the IMA safety feature, and why?

____

____

6. I would like to have IMA on my personal vehicle.

1	2	3	4	5	6	7
Strongly Disagree						Strongly Agree

18

Please indicate your overall acceptance rating of the Intersection Movement Assist warnings.

For each choice you will find five possible answers. When a term is completely appropriate, please put a check (√) in the square next to that term. When a term is appropriate to a certain extent, please put a check to the left or right of the middle at the side of the term. When you have no specific opinion, please put a check in the middle.

The **Intersection Movement Assist warnings** were:

Useful						Useless
Pleasant						Unpleasant
Bad						Good
Nice						Annoying
Effective						Superfluous
Irritating						Likeable
Assisting						Worthless
Undesirable						Desirable
Raising alertness						Sleep-inducing

Questions about system acceptance

For questions 1-2, on a scale of 1 to 7 where 1 is "Not at all Willing" and 7 is "Completely Willing", how willing would you be to…

1. …have Connected Vehicle technology on your vehicle if it required periodic visits to your auto dealer or some other location for updates to ensure proper system operation?

1	2	3	4	5	6	7

2. …have Connected Vehicle technology on your vehicle that, when combined with other information may allow:

   a. A business entity to learn about your vehicle's location and travel patterns?

1	2	3	4	5	6	7

   b. The government to learn about your driving behavior and patterns?

1	2	3	4	5	6	7

   c. A third party organization to learn about your driving behavior and patterns?

1	2	3	4	5	6	7

   d. Appropriate personnel to determine criminal behavior such as hacking?

1	2	3	4	5	6	7

20

Demographic information

1. In which of the following categories is your age?
    a. 18 to 24
    b. 25 to 34
    c. 35 to 44
    d. 45 to 54
    e. 55 to 64
    f. 65 or older

2. Are you…?
    a. Male
    b. Female

3. Which of the following statements best describes you?
    a. I prefer to be the first to buy and try new technologies
    b. I prefer to wait until new product hype has calmed before I purchase and try new technologies
    c. I prefer to wait until new technologies have been thoroughly tested and reviewed, and others I know have purchased and used new technologies before I purchase
    d. None of the above

4. Do you currently have any of the following advanced technologies on your personal vehicle? [MULTIPLE RESPONSE]
    a. Adaptive Cruise Control
    b. Blind Spot Detection/Warning
    c. Forward Collision Alert
    d. Rearview Camera
    e. Lane Departure Warning/Assist
    f. Other   If other, please list:________________________
    g. None
    h. DON'T KNOW

5. Approximately how many miles do you drive your primary vehicle per week?
    a. 0 to 49 miles
    b. 50 to 99 miles
    c. 100 to 199 miles
    d. 200 to 299 miles
    e. 300 to 499 miles
    f. 500 miles or more
    g. DON'T KNOW

6. What is the last grade you completed in school?
    a. Some grade school (1-8)
    b. Some high school (9-11)
    c. High school graduate (12)
    d. Technical or vocational school
    e. Some College
    f. College Graduate
    g. Graduate or Professional School
    h. Other

7. Select one or more of the following that best describes your race? [ACCEPT MULTIPLE RESPONSES]
    a. American Indian or Alaskan Native
    b. Asian
    c. Black or African-American
    d. Hispanic or Latino descent
    e. Native Hawaiian or other Pacific Islander
    f. White

8. Which ONE of the following best describes your total household income?
    a. Under $25,000
    b. $25,000 to less than $50,000
    c. $50,000 to less than $75,000
    d. $75,000 to less than $100,000
    e. $100,000 to less than $150,000
    f. $150,000 to less than $200,000
    g. $200,000 or more
    h. Prefer not to respond

22

Appendix B: Video Analysis Coding Scheme

This appendix lists all variables that are coded during the video analysis of safety application alerts. The intent of the video analysis is to capture information that is not available in the numerical database or to validate the numerical data. The captured analysis variables vary by safety application.

Crash Type

- *Pre-crash scenario*: the configuration of vehicles and vehicle dynamics prior to the alert (all alert types).

Driver Attention

- *Eyes off driving task*: was the driver's attention not focused on the driving task at the time of the event (all alert types).
- *Task responsible for eyes off driving task*: the non-driving activity that took the driver's attention away from the road (all alert types).
- *Eyes off threat*: was the driver's attention not focused on a vehicle that was posing a threat (all alert types).
- *Other secondary tasks*: (all alert types).

Host Vehicle

- *HV maneuver*: the maneuver of the vehicle at the time of the event (all alert types).
- *HV location*: curved road, straight road, intersection, ramp, etc. (all alert types).
- *Steering response to threat*: did the driver respond to the scenario with a steering maneuver (all alert types).
- *HV position within lane*: in lane, between lanes, fully in adjacent lane (FCW, LCW).

Environmental

- *Lighting*: day/night (all alert types).
- *Weather*: clear/rain/snow (all alert types).

Lead Vehicle Target

- *Forward target lane location*: is the RV in-path of the HV (FCW, EEBL).
- *Forward target driving maneuver*: what is the RV doing at alert time (FCW, EEBL).
- *Forward target road position*: straight road, curved road, etc. (FCW, EEBL).
- *Obstructing vehicle*: is a vehicle present between the host and RV (EEBL).

Side Target

- *Side target lateral position*: adjacent, 2 lanes over, in lane, other (LCW).

Intersection Target

- *IMA target maneuver*: the maneuver/location of the IMA target (IMA).
- *IMA target direction*: left/right (IMA).
- *Post encroachment time (PET)*: the time to point of intersection of the RV after the HV has passed (IMA where host passes in front of remote).
- *Traffic control device*: stop sign, traffic signal, etc. (IMA).

- *View obstructed*: was the driver’s view of oncoming traffic obstructed (IMA, left turn across path (LTAP), left turn into path (LTIP)).

Opposite Direction Target

- *Opposite direction target location*: adjacent lane, two lanes over, other (LTAP, do not pass warning (DNPW)).
- *Road geometry*: did the alert occur on a two-lane, opposite direction road (DNPW).
- *Driver intent to pass*: did the driver of the HV intend to pass the RV (DNPW).
- *Time to collision at warning time*: the time to the collision point with the RV at the warning onset (DNPW).

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