Independent Evaluation of the Transit Retrofit Package Safety Applications

Final Report

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16. Abstract

This report presents the methodology and results of the independent evaluation of retrofit safety packages installed on transit vehicles in the Safety Pilot Model Deployment—part of the United States Department of Transportation's Intelligent Transportation Systems research program. The Model Deployment included approximately 2,800 vehicles, equipped with designated short-range-communication-based vehicle-to-vehicle and vehicle-to-infrastructure technology in a real-world driving environment. The goals of the independent evaluation were to assess system performance, safety impact, and driver acceptance of the vehicle-to-vehicle safety applications based on the naturalistic driving of 75 drivers who drove the equipped transit buses during the Model Deployment. The results of the analysis suggest that the TRP safety applications have the potential to improve driver behavior and increase driver safety, but improvements in accuracy are needed. Results from the Model Deployment will help shape future research direction.

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Executive Summary

This report presents the methods and results of the independent evaluation of the Transit Retrofit Package (TRP) vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) safety applications in the Safety Pilot Model Deployment. The Safety Pilot Program is part of the United States Department of Transportation's (U.S. DOT) Intelligent Transportation Systems (ITS) research program and focuses on the development and evaluation of crash avoidance systems. These systems are based on V2V and V2I technologies that communicate through dedicated short range communication (DSRC).The vision of the Safety Pilot Program is to test DSRC-based safety applications in real-world driving scenarios to determine their effectiveness at reducing crashes, and to ensure that the technology does not cause negative unintended consequences.

The U.S. DOT's Volpe National Transportation Systems Center is the Independent Evaluator (IE) for the Safety Pilot program. The goals of the Safety Pilot evaluation are to:

- Characterize system performance of the V2V and V2I- based safety applications
- Assess the safety impact of the V2V and V2I-based safety applications
- Determine driver acceptance of the V2V and V2I-based safety applications

Methodology

This evaluation is based on data collected from TRP-equipped buses during the Safety Pilot Model Deployment—a one-year naturalistic field test of 2,800 light vehicles, heavy trucks, and transit buses equipped with DSRC devices and V2V and V2I safety applications—conducted in a real-world environment on public roadways in Ann Arbor, MI by the University of Michigan Transportation Research Institute (UMTRI).

During the Safety Pilot Model Deployment, professional transit bus drivers drove three University of Michigan transit buses equipped with the TRP safety applications during three test periods: the Baseline period, where the TRP was operating in the background but no alerts were issued to the drivers; the Model Deployment test period, where the TRP safety applications were enabled; and the Redeployment, where an improved version of the TRP was implemented.

The TRP buses were equipped with five (three V2V and two V2I) safety applications:

- V2V safety applications:
  - *Forward-collision warning (FCW):* warns the driver of stopped or slower vehicles ahead
  - *Emergency brake light warning (EEBL):* warns the driver of heavy braking ahead in the traffic queue
  - *Vehicle turning right in front of bus warning (VTRW):* warns the driver if a vehicle is attempting to navigate around the bus and turn right in front of the bus when it is stopped at a designated bus stop

- V2I safety applications:
  - *Curve speed warning (CSW):* warns the driver if the bus is going too fast when approaching an equipped curve
  - *Pedestrian in signalized crosswalk warning (PCW):* warns the driver if pedestrians are in the intended path of the bus when it is making a right or left turn at the equipped intersection, or if a pedestrian pushes the crosswalk button

System Performance

The evaluation looked at the ability of the safety applications to appropriately issue warnings in the Safety Pilot Model Deployment environment. The IE categorized crash-imminent alerts based on the target 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.

Key Findings

FCW

- Overall, 41 percent of FCW alerts were issued for in-lane remote vehicles (true alerts).
- FCW alerts issued for moving remote vehicles were more accurate than FCW alerts issued for stopped remote vehicles (53 percent of alerts issued for in-path targets for moving remote vehicles, and 23 percent of alerts issued for in-path targets for stopped remote vehicles).
- The IE observed 4 scenarios that appear to be missed FCW alerts during the Model Deployment field test. Three of the potential missed FCW events occurred when the host vehicle was traversing a curve, suggesting that curved road scenarios may impact the FCW applications' ability to properly identify and locate a relevant remote vehicle.

CSW

- Fifty-seven percent of CSW alerts were issued when the TRP bus was either entering or traversing the equipped curve (true alerts).
- CSW alerts issued when the TRP bus approaching the Bonisteel Boulevard equipped curve from the south were much more accurate than alerts issued when the bus was approaching from the east (100 percent true alerts when approaching from the south compared to 36 percent true alerts when approaching from the east).
- The IE observed 22 missed CSW alert scenarios during the Model Deployment field test. Missed CSW alerts could be caused by errors in the safety application software, or the functionality of CSW infrastructure.

EEBL

- Over 90 percent of EEBL alerts during the Model Deployment field test were true alerts (23 of 25). The remaining 2 alerts were issued for vehicles that were on adjacent roadways and therefore not a threat to the TRP bus.

PCW

- The performance of the PCW improved based on the modifications made prior to the Redeployment test period.
  - Of the PCW alerts where the presence of a pedestrian could be confirmed, 12 percent were true during the Model Deployment test period and 24 percent were true during the Redeployment.
  - Twenty percent of the PCW alerts during the Model Deployment were issued when the bus went straight through the intersection (did not traverse the equipped crosswalk), but only 9 percent of PCW alerts from the Redeployment were issued in this scenario.
- The PCW application could be improved by tailoring the timing of the warnings so that they are issued only when the driver is proceeding, or about to proceed, into the equipped crosswalk.

VTRW

- During the Model Deployment test period, 14 percent of the cautionary VTRW alerts and 22 percent of the imminent VTRW alerts were issued in scenarios where the remote vehicle followed the prescribed path (true alerts). False alerts were primarily caused by inaccurate relative positioning of the remote vehicle.
- The VTRW application performance improved from the Model Deployment test period to the Redeployment in terms of driver intent at the time of the alert:
  - Forty-five percent of Model Deployment VTRW alerts were issued when the bus driver was intending to depart the bus stop.
  - Eighty-six percent of Redeployment VTRW alerts were issued when the bus driver was intending to depart the bus stop.

Safety Impact

During the three Model Deployment test periods the IE looked at driver response to TRP application alerts for each safety application and at driver attention to the driving task.

Driver Response to Alerts

For each safety application, driver performance metrics were compared.

FCW

- The IE observed a slight decrease in response time to FCW alerts for decelerating remote vehicles between the Baseline and Model Deployment/Redeployment test periods, but the decrease was not significant.

CSW

- Drivers braked within 5 seconds of less than 10 percent of CSW alerts issued during the Baseline and Model Deployment test periods, but braked within 5 seconds of 60 percent of alerts issued during the

Redeployment. No changes were made to the application software between test periods, suggesting that this change in driver behavior was due to changes made to the driver interface.

- There was a statistically significant increase in both peak and mean longitudinal deceleration within 5 seconds of a CSW alert between the Baseline and Model Deployment, the Model Deployment and the Redeployment, and the Baseline and the Model Deployment and Redeployment test periods combined. The increase in peak deceleration from the Model Deployment to Redeployment is likely due to the increased response rate, as a braking maneuver will create higher deceleration levels than when there is no braking maneuver.
- There was a statistically significant decrease in both peak and mean lateral acceleration from the Model Deployment to the Redeployment test periods within 5 seconds of a CSW alert, indicating that drivers traversed the CSW-equipped curve less aggressively during the Redeployment.

EEBL

- The IE did not observe changes in mean or peak deceleration within 5 seconds of EEBL alerts between the Baseline and the Model Deployment and Redeployment test periods combined. It is important to note that the sample size of EEBL alerts was very small, making it difficult to observe trends between test periods.

PCW

- The IE did not observe any differences in driver response to PCW alerts between the Model Deployment and Redeployment test periods.
- Drivers braked in response to 4 of 37 true PCW events. Fourteen of the 37 true PCW alerts were issued when the bus was stopped at the intersection (no response required), 6 were issued when the driver was already braking or braking for reasons other than the pedestrian presence, and drivers did not respond to 11 of the events because the pedestrian had already cleared, or was clearing the intersection.

VTRW

- Drivers did not show a visible response to any of the 11 true VTRW alerts observed during the Model Deployment.

Driver Attention

Secondary Tasks

- The IE observed very few instances of the TRP drivers preforming secondary tasks (activities unrelated to the driving task such as eating or using a cellular phone).
- Drivers were much more likely to perform secondary tasks during a PCW or VTRW alert, probably because these alert types can be issued when the bus is stationary.

Distraction

- The IE did not observe any instances of unintended consequences or negative behavior adaptations from driving with the TRP safety applications.

Driver Acceptance

Usability

- Drivers generally found the TRP to be easy to use, giving the CSW the highest rating and the FCW the lowest. The alerts were considered easy to see (particularly after improvements were made to the TRP prior to the Redeployment test period) and to understand.
- Participants also thought the different types of alerts were distinguishable from each other.

Perceived Safety Benefits

- Participants did not view the safety applications as providing many safety benefits, mainly because they viewed themselves as skilled drivers, already aware of potential collision scenarios before the system alerted them.
- Participants thought the system would be more useful for inexperienced drivers in bigger cities where traffic tends to be more complex and aggressive.
- Participants also had little trust in most alerts, due to the number of false alerts they felt they received.
- Nonetheless, the perception of the increase in safety from using the system increased during the Redeployment. This may have been an experimental effect since participants knew they were testing modifications designed to improve the system (there was no control or counterbalance for this effect).

Unintended Consequences

- The risk for unintended consequences was mostly neutral, with some participants reporting concern that the displays could distract one from the road.
- Generally the system was not seen as accurate enough to rely on. Only a minority of participants (2 out of 3 Top-7 participants) noticed changes in their driving behavior and overreliance was not identified as one of these changes.

Desirability

- Both the surveys and focus groups showed very little desire for the system.
- Among the individual applications, the CSW was most desired for its accuracy and usefulness. The FCW was least desired, especially due to false alerts (the ease of use and understanding of the FCW were not negatively reviewed). The PCW was liked for its understandability but was still regarded neutrally for desirability. None of the participants actually received a VTRW warning, but they nonetheless liked the idea of it and thought it could be the most helpful of the applications. The limited feedback on the EEBL was largely neutral.

Privacy

- Concern for privacy was mixed and largely neutral.
- Expectations of privacy are also different for bus drivers since they are on the job and not driving their personal vehicles. Nonetheless, one participant was concerned that the system might be hacked and that their driving information would be made available to insurance companies who would then raise their rates.

- Another factor unique to bus drivers (not applicable for people driving their personal vehicles or for commercial truck drivers) is the presence of passengers and the importance of their perception of the system to the driver. One participant was embarrassed by alerts visible to passengers that might give the impression that the participant was a bad driver (complaints could impact a driver's job security).

Conclusions

Overall, the Safety Pilot Model Deployment demonstrated that TRP safety applications can be deployed in a real-world driving environment. The experimental design was successful in creating naturalistic interactions between the TRP buses and other DSRC-equipped vehicles and infrastructure. The safety applications successfully issued warnings in the safety-critical driving scenarios that they were designed to address.

The Model Deployment played a crucial role in revealing areas for improving the performance of the prototype safety applications, which could not have been identified in controlled testing environments. Some of these improvements were implemented and tested during the Redeployment test period, while others require future research.

1 Introduction

This report presents the analytical approach and results of the independent evaluation of the Transit Retrofit Package (TRP) safety applications in the Safety Pilot Model Deployment. The Safety Pilot program is part of the United States Department of Transportation's (U.S. DOT) Intelligent Transportation Systems (ITS) research program, and focuses on the development and evaluation of crash warning and avoidance systems. These systems are based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies that communicate through dedicated short range communication (DSRC) at 5.9 GHz. The U.S. DOT goal for this program is to accelerate the introduction and commercialization of the DSRC-based crash avoidance 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 Safety Pilot is to test V2V and V2I safety applications in real-world driving scenarios to determine their effectiveness at reducing crashes, and to ensure that the technology does not cause unintended consequences.

The U.S. DOT's John A. Volpe National Transportation Systems Center (Volpe) is the Independent Evaluator (IE) for the Safety Pilot. The independent evaluation of the Safety Pilot is based on the data collected during the Safety Pilot Model Deployment—a naturalistic real-world V2V and V2I field test of 2,800 V2V-equipped light vehicles, heavy trucks, and transit buses—conducted in Ann Arbor, MI. The University of Michigan Transportation Research Institute (UMTRI) is the Test Conductor for the Model Deployment.

This report evaluates V2V and V2I TRP safety applications that were installed on three University of Michigan transit buses.

1.1 Transit Retrofit Package

The TRPs were installed on three University of Michigan transit vehicles (see Figure 1-1) that traveled between university parking lots and various parts of the University of Michigan campus and medical center. The TRP consists of a wireless safety unit that sends, receives, and processes basic safety messages (BSMs) containing information about vehicle location and heading; and an in-vehicle tablet display that performs computations related to the safety applications and provides visual and auditory warnings to the driver. The tablet display is discussed in more detail in Section 4.2. For a complete list of TRP documentation refer to the "Transit Safety Retrofit Package Development Final Report" [1].

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Figure 1-1. University of Michigan Transit Buses

1.1.1 Safety Applications

The TRP buses had three V2V and two V2I safety applications that provided crash-imminent and advisory warnings to the drivers. A crash-imminent warning alerts the driver to an immediate threat, while an advisory (or cautionary) warning provides information that may help improve the driver's situational awareness. In this report, crash-imminent and advisory warnings are also referred to as "red" and "yellow" warnings, respectively.

The V2V safety applications installed in the TRP buses include:

- *Forward-collision warning (FCW):* warns the driver of stopped or slower vehicles ahead
- *Emergency brake light warning (EEBL):* warns the driver of heavy braking ahead in the traffic queue
- *Vehicle turning right in front of bus warning (VTRW):* warns the driver if a vehicle is attempting to navigate around and turn right in front of the bus when it is stopped at a designated bus stop

The V2I safety applications installed in the TRP buses include:

- *Curve speed warning (CSW):* warns the driver if they are going too fast when approaching an equipped curve
- *Pedestrian in signalized crosswalk warning (PCW):* warns the driver if pedestrians are in the intended path of the bus when it is making a right or left turn at the equipped intersection, or if a pedestrian pushes the crosswalk button

Battelle Memorial Institute, along with Denso developed and implemented the safety applications on the TRP buses in the Safety Pilot Model Deployment. The FCW, EEBL and CSW applications were implemented on TRP buses as well as other vehicle types in the Safety Pilot Model Deployment (light vehicles and heavy trucks); whereas Battelle developed the VTRW and PCW safety applications specifically to address the unique safety needs of transit buses.

With the exception of the VTRW application, this analysis addresses only the crash-imminent component of the safety applications. Very few crash-imminent VTRWs were observed in Model Deployment, so both cautionary and crash-imminent VTRWs were addressed (see Section 1.2.4).

1.1.2 Infrastructure

The following infrastructure supports the two V2I safety applications:

- *CSW-equipped curve: Roadside Safety Equipment (RSE):* broadcasts the safe travel speed of the equipped curve
- *Pedestrian detection system:* microwave sensors detect the presence of pedestrians in the equipped crosswalk and a roadside unit broadcasts pedestrian presence as a part of the Signal Phase and Timing (SPAT) message.

1.2 Model Deployment

This evaluation is primarily based on data collected from the TRP buses during the Safety Pilot Model Deployment from October 2012 to March 2014 on public roadways in Ann Arbor, MI. Approximately 2,800 vehicles were equipped with DSRC devices. The goal of the Model Deployment was to collect performance data on DSRC technology and on DSRC-based safety applications operating in real-world conditions.

In addition to TRP buses, the Model Deployment field test included four different types of DSRC devices:

- *Integrated Vehicles (IV)* – DSRC systems and driver interfaces built in to the vehicle (both passenger cars and heavy trucks) by the manufacturer
- *Aftermarket Safety Devices (ASD)* – aftermarket DSRC systems devices and driver interfaces
- *Retrofit Safety Devices (RSD)* – aftermarket DSRC systems and driver interfaces integrated into the vehicle's computer network
- *Vehicle Awareness Device (VAD)* – DSRC devices that broadcast information but do not receive messages or issue safety application alerts to drivers

1.2.1 Experimental Design

The Model Deployment data collection for TRP buses was broken down into three test periods (Table 1-1). During the Baseline test period, drivers drove the TRP-equipped bus without receiving warnings, during Model Deployment the safety applications were enabled, and during Redeployment drivers used an improved version of the TRP (see Section 1.2.3 for details of the TRP Modifications).

Table 1-1. TRP Model Deployment Test Periods

Test Period	Description	Duration
Baseline	For the first part of the field test, the FCW, EEBL, and CSW applications were enabled but the driver vehicle interface (DVI) did not provide warnings to the drivers (applications were operating in the background). PCW and VTRW applications were not enabled.	2 months

Test Period	Description	Duration
Model Deployment	All applications were enabled and drivers received application warnings.	8 months
Redeployment	An improved driver interface. PCW and VTRW applications were deployed. FCW, EEBL, and CSW applications continued to function as they did during Model Deployment.	1 month

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1.2.2 Participants

Participants in the Model Deployment who drove the TRP buses were employees of the University of Michigan Transit System. Drivers were a mix of professional drivers and student drivers. During the Baseline and Model Deployment test periods combined, five drivers drove the TRP buses full time and 35 part time, i.e., they rotated between TRP and regular buses. This made for a total of 40 drivers. Figure 1-2 shows the distribution of driving hours during the Model Deployment test period; the five drivers using the TRP buses full time drove a combined 83 percent of the total driving hours, while the 35 part-time users drove the remaining 17 percent.[1]

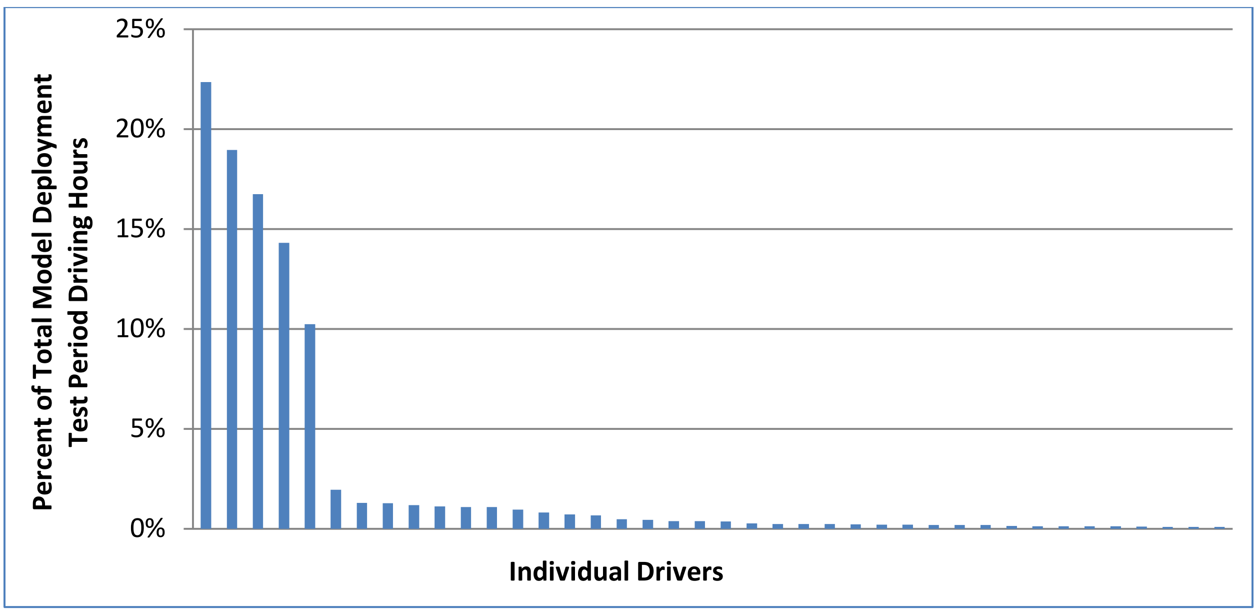

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Figure 1-2. Percentage of Model Deployment Driving Hours by Individual Drivers

[1] Data are not available for the distribution of driving hours during the Baseline test period, however the drivers of the TRP buses did not change from the Baseline to the Model Deployment test periods, so the distribution of driving hours is expected to be similar.

During the Redeployment, the TRP buses were driven by 35 drivers (four drove them full time and 31 part time). About half of the drivers who drove during the Redeployment also drove during the Baseline and Model Deployment test periods, while the remaining drivers drove the TRP buses for the first time.

Drivers were recruited through their employer, the University of Michigan Transit. Employees were given the opportunity to opt-in to participate in the study. Drivers who primarily drove the routes that the TRP buses were designated to travel on were given priority for participation. The Transit Safety Retrofit Package Development Final Report [1] provides a detailed description of driver recruitment and training procedures.

1.2.3 Safety Application Software Modifications

Based on application performance during the Model Deployment test period and feedback from drivers, Battelle modified the TRP software and hardware prior to the launch of the Redeployment. These modifications are summarized below. For more details refer to the Transit Safety Retrofit Package Development Final Report [1].

- Driver interface
    - Moved tablet display closer to the driver
    - Changed auditory warnings from tones (beeps) to a more verbal message
    - Increased the duration of the visual display from two seconds to three seconds
- PCW application
    - Decreased the threshold speed for pedestrian detection (to reduce alerts caused by vehicles traversing the crosswalk)
    - Increased the time threshold for pedestrian detection (to increase confidence of pedestrian detection)
    - Decreased tolerance for determining that the bus is in the designated turn lane (to increase accuracy of alerts based on the path of the bus)
    - Decreased the size of the geographic location where alerts can be issued (to decrease alerts issued after the bus has already crossed through the equipped intersection)
- VTRW application
    - Suppressed warnings if the bus transmission is not in drive (to reduce alerts issued when the bus is parked)

1.2.4 Summary of Exposure

The following subsections summarize the TRP exposure to safety application alerts and the availability of the PCW infrastructure during the Model Deployment field test.[2]

1.2.4.1 Exposure to Application Alerts

Overall 3,317 crash-imminent safety application alerts were issued to TRP drivers during the Model Deployment Field test.[3] Figure 1-3 breaks the events down by safety application and test period. The FCW

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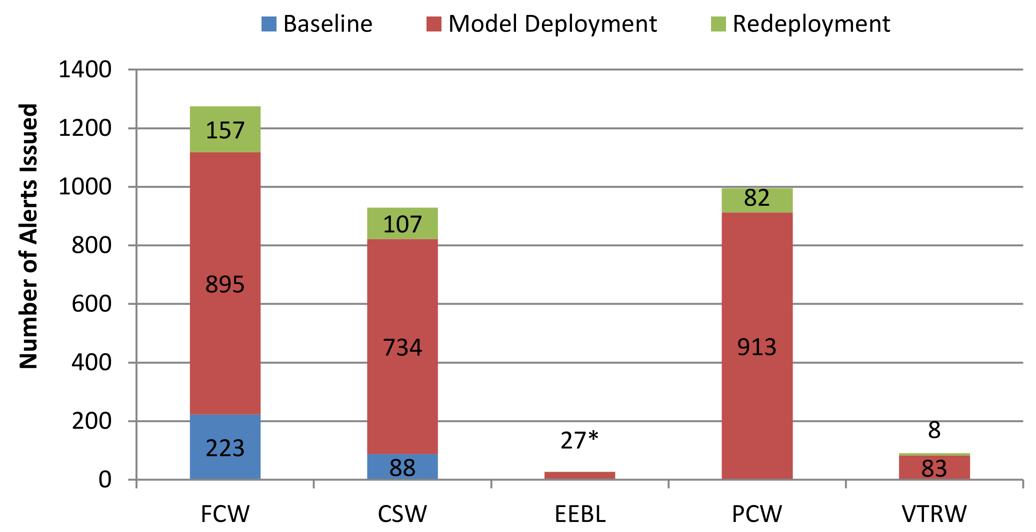
[2] Data were not available on the availability of CSW infrastructure, so these results are not included in the summary of infrastructure availability.

[3] Multiple alerts from the same application issued within three seconds of each other were considered to be only one alert event, since drivers are unlikely to recognize events issued in close proximity as individual events.

application issued alerts most frequently (1,275 total events) and the EEBL application issued alerts least frequently (27 events).



*Total in all three test periods. Breakdown is as follows: Baseline = 4 alerts, Model Deployment = 22 alerts, Redeployment = 1 alert

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Figure 1-3. Number of TRP Alerts Issued by Safety Application and Test Period

1.2.4.2 Availability of PCW Infrastructure

The TRP drivers traversed through the PCW-equipped intersection 5,793 times during the Model Deployment field test (2,801 when making a left turn and 2,992 when making a right turn). The PCW infrastructure was active (the TRP bus received a message from the infrastructure when approaching the intersection) during 54 percent of those infrastructure traverses (57 percent of left turns and 54 percent of right turns), meaning that the PCW safety application was available to TRP drivers 54 percent of the time they passed through the equipped intersection during the Model Deployment field test.

Figure 1-4 shows the breakdown of PCW infrastructure availability by calendar month. Availability varied considerably by time period. During October 2012 the TRP buses were operating and collecting data, but the infrastructure was not yet enabled. During October 2013 the infrastructure was disabled so repairs could be made. During the months that the PCW was enabled, it was operational for 56 percent of the intersection traverses during the Baseline test period, 40 percent of traverses during the Model Deployment test period, and 72 percent of traverses during the Redeployment test period.

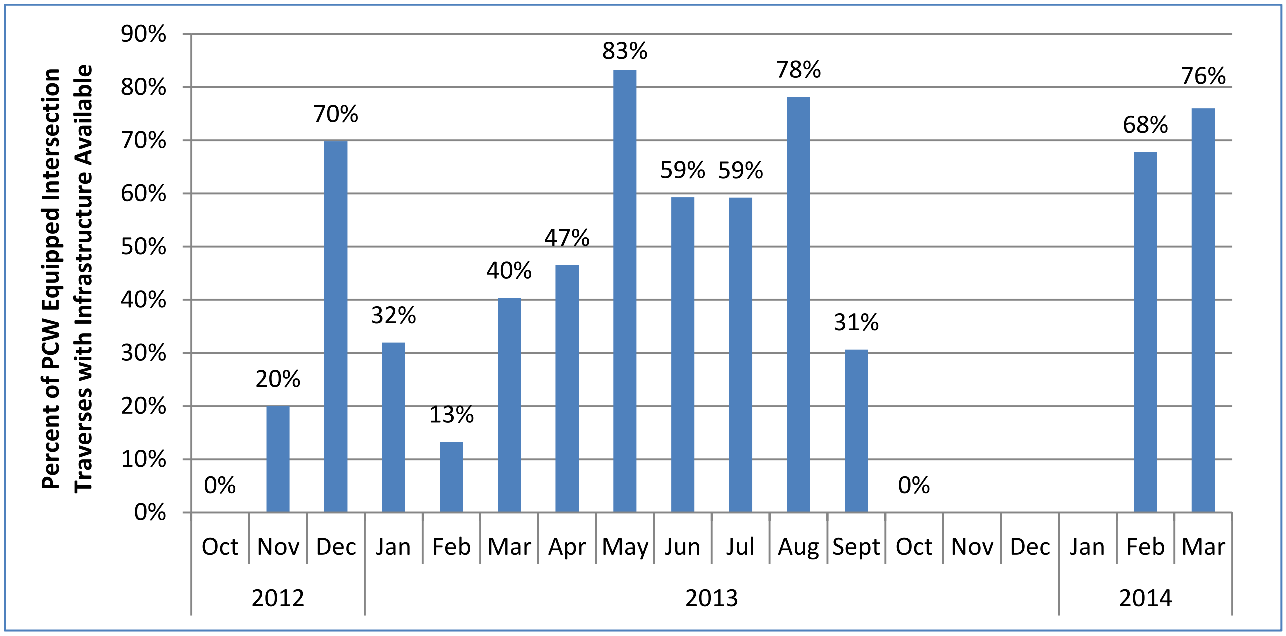

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Figure 1-4. PCW Infrastructure Availability by Calendar Month

1.3 Evaluation Goals

The goals of the evaluation of the Safety Pilot Model Deployment TRP safety applications are to:

1. **Characterize system performance.** This goal addresses the ability of the safety applications to appropriately issue warnings in the Model Deployment environment.
2. **Assess the safety impact of the V2V and V2I safety applications.** This goal addresses the impact that the safety applications have on driver behavior and performance.
3. **Determine driver acceptance of the safety applications.** This goal addresses the usability of the safety applications from a driver perspective; whether or not participants perceive there is a safety benefit from using the technology, understand the warnings and the driver interface, and have concerns about security and privacy if this technology were to be deployed.

1.4 Data Sources

The IE used data collected during Model Deployment Field Test to evaluate the TRP safety applications in the Safety Pilot. There are two primary types of data; objective and subjective.

1.4.1 Objective Data

Objective data consist of numerical and video data. Data were collected by a Data Acquisition System (DAS) connected to the vehicle's Controller Area Network (CAN) bus, DSRC device, and other external sensors. Data collection begins when the ignition of the equipped vehicle is turned on.

The numerical data were collected and stored at a rate of 10 Hz. There are four data categories:

- *In-vehicle data*: information 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 TRP bus position within the lane (e.g., lane tracking/forward radar)
- *Application data*: information about when and why types of alerts are being issued to the participants

- Four video views were captured and synchronized with the numerical data. The video views were selected based on the field of view needed to validate the TRP safety application alerts.

Figure 1-5 shows the video views for the TRP data. These include (clockwise from top left):

- Forward-left side
- Forward-right side
- Driver face/cabin
- Left rear

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Figure 1-5. TRP Video Views

UMTRI collected the objective data from the TRP buses. Over 330 million numerical data records (i.e., lines of data—for most data elements one line of data is collected every 1/10th of a second) and over 9,300 hours of video data were collected from the TRP buses during the field test. Appendix B lists all objective data elements.

1.4.2 Subjective Data

TRP drivers were encouraged to complete a questionnaire at the end of their participation in the Model Deployment and again after Redeployment. Of the 40 drivers who drove during the Model Deployment test period 32 completed the questionnaire. Of the 35 drivers who drove during the Redeployment test period 27 completed the questionnaire.

The questionnaire consisted of open-ended questions, multiple choice questions, and questions answered using a seven-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 1-6. After a preliminary section containing questions about the overall suite of safety features, the survey then broke down into separate sections for each application. Post drive surveys from both the Model Deployment and Redeployment are located in Appendix D.

Drivers were also invited to participate in focus groups at the end of both the Model Deployment and Redeployment test periods. The purpose of the focus groups was to acquire more in-depth driver acceptance feedback from the TRP drivers. Five drivers attended the focus group held after the Model Deployment test period and three drivers attended the focus group after the Redeployment test period. Focus group questions are listed in Appendix E.

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

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Figure 1-6. Likert Scale Question Format Used on Driver Acceptance Questionnaire

1.5 Mapping of Data Sources to Goals

Table 1-2 shows the data sources used to address each of the three evaluation goals summarized in Section 1.3. The system performance and safety impact goals used only objective data, while the driver acceptance goal used subjective data.

Table 1-2. Breakdown of Evaluation Data and Goals

Evaluation Goal	Objective Data	Subjective Data
System Performance	X	
Safety Impact	X	
Driver Acceptance		X

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2 System Performance

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

The IE addresses the observed performance of the safety applications during the Safety Pilot Model Deployment field test. Results are based on the visual inspection of video data and backed by relevant numerical data. The IE does not attempt to explain the root cause of false or missed alerts.

In this section, results for FCW, CSW and EEBL represent all three test periods, since no changes were made to these applications during the field test that impacted application performance. Since changes to improve the performance of the PCW and VTRW safety applications were implemented prior to the Redeployment test period, results for these applications are broken down by test period.

2.1 Technical Approach

This subsection describes the technical approach used to characterize the performance of the V2V and V2I safety applications in the Model Deployment.

Crash-imminent alerts were categorized based on the target location and driving scenario when application alerts were issued. Alerts were classified as true[4] or false based on the type of driving scenario each individual application was designed to address. In addition to examining alerts, the IE looked at false negatives (missed alerts); scenarios where a valid warning trigger was present and basic alert conditions were satisfied, and alert was not issued. Table 2-1 lists alert classifications based on target location.

Table 2-1. Alert Classification by Target Location

	Target, In-Position	Target, Out of Position	No Target
Alert	True Alert	False Alert	False Alert
No Alert	Missed Alert	Valid Rejection	Valid Rejection

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[4] True alerts are alerts issued in scenarios where the information provided by the alert is potentially helpful to the driver.

The IE analyzed the safety application performance based on whether or not the application addressed the intended safety need by providing useful information to the driver, not based on the software's ability to perform as intended. Battelle also performed a complete analysis of the application software performance [2]. This report identifies differences between these two analyses.

As described in Section1.2.3, Battelle made software changes to the PCW and VTRW safety applications prior to the redeployment of the TRP buses [2]. For these safety applications, the performance in the Model Deployment and the Redeployment test periods were analyzed separately. For the FCW, EEBL and CSW applications, the Baseline, Model Deployment, and Redeployment test periods were combined for all system performance analyses.

2.1.1 Alert Accuracy

The IE conducted alert classifications using a video analysis tool developed by the Volpe Center. This tool synchronizes and displays video from 10 seconds before and 5 seconds after each application alert, in addition to the corresponding numerical data from the database. The tool allows analysts to validate the position of the remote vehicle (RV)[5] and the dynamics of both vehicles at the time of the alert. Analysts use 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 2-1. The coded variables include information about the location of the vehicles at the time of the alert, the driving maneuvers of both vehicles, and the behavior of the driver, the driver's response to the alert, and environmental conditions. Appendix C lists all coded variables and definitions.

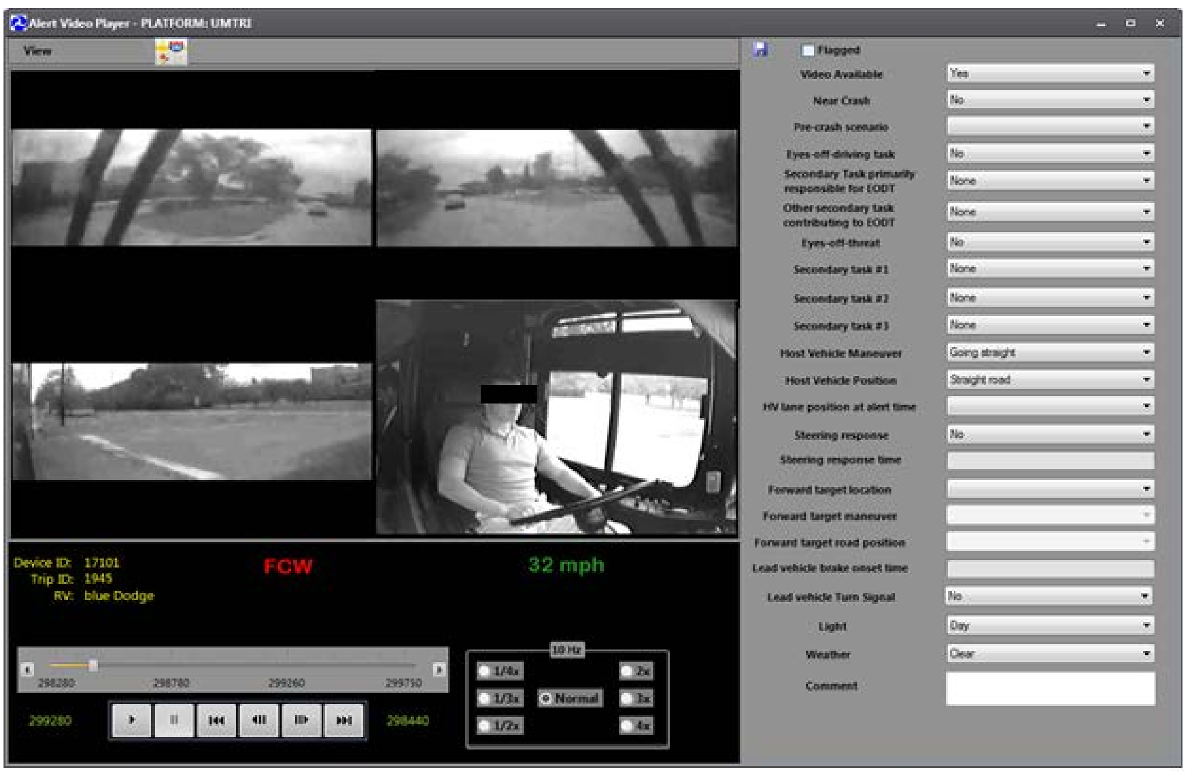

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Figure 2-1. Video Analysis Tool

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[5] The DSRC equipped vehicle that triggered the application alert. Also referred to as the "target vehicle,"

Table 2-2 shows the primary attribute used to assess performance for each of the TRP safety applications and the value that indicates that the alert is a true alert.

Table 2-2. Classification Variables and Values of Safety Application Accuracy Analysis

Safety Application	Classification Variable(s)	Possible Values	True Alert Value
FCW	Forward target location	In-path, one lane over, two lanes over, other	In-path
CSW	Bus position within curve	Curve entry, in curve, curve exit, not at equipped curve	Curve entry, in curve
EEBL	Target location	Ahead, other	Ahead
PCW	Presence of pedestrians	In crosswalk, on sidewalk, none	In crosswalk
VTRW	Side target location at alert onset	Adjacent, two lanes over, in front	Adjacent
	Side target approach location	Behind (in- lane), adjacent lane, two lanes over	Behind (in-lane)

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Additional variables used in the alert classification breakdowns include:

- Remote vehicle motion (moving/stopped)
- Road geometry
- Target device type (integrated vehicle, aftermarket safety device, vehicle awareness device, heavy truck, etc.)
- Test period (Model Deployment/Redeployment)

Due to the large number of crash-imminent FCW, CSW and PCW alerts issued to the drivers, the IE selected a random sample of alerts from each of these safety applications. The sampling method targeted approximately half of the alerts from each test period for analysis.[6] For EEBL and VTRW, where fewer alerts were issued, all alerts were analyzed. For some VTRW events, one or more of the video views required to analyze the event was either obstructed or not available, resulting in the analysis of 86 percent of alerts overall.

Figure 2-2 shows the total number of alerts analyzed by safety application. Numbers in parentheses in each bar represent the percentage of total alerts that were analyzed.

[6] For some events, the video or numerical data required to analyze an alert was not available. In an attempt to have a final result of half of events analyzed, the sampling method identified slightly more than half of the alerts from each application for analysis. This method resulted in slightly more or less than 50 percent of alerts analyzed from each application overall.

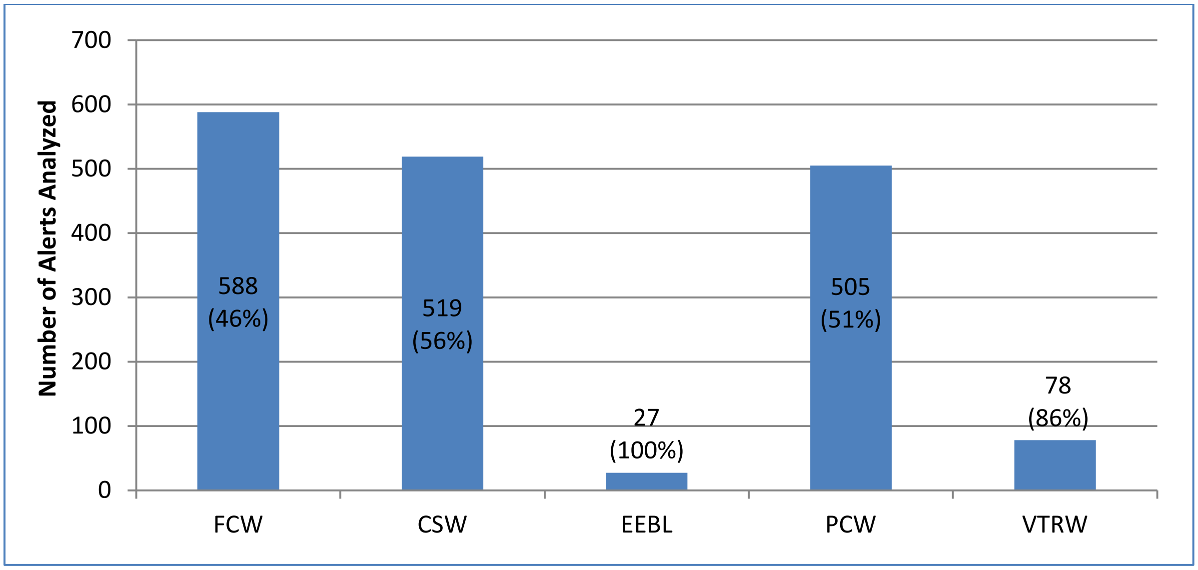

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Figure 2-2. Number and Percentage of Alerts Analyzed, by Safety Application

2.1.2 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. The IE took an exploratory approach to the analysis of missed alerts by identifying driving scenarios that were the same as the scenarios where valid alerts were issued but did not trigger an application alert. This approach was not intended to be exhaustive, but rather to gain anecdotal insight into the types of scenarios in which alerts were potentially missed.[7]

The following subsections cover missed alert analysis for FCW, CSW, and VTRW warnings. For each application, driving scenarios were identified that satisfied the known criteria required for an alert to be issued. EEBL and PCWs are not included in the missed alert analysis because the data elements required to detect missed alerts were not collected as part of the dataset.

2.1.2.1 FCW

The IE detected potential missed FCW alerts using an algorithm that identified scenarios where the TRP bus had a hard braking response to a V2V-equipped lead vehicle, but did not receive an FCW alert.

Potential missed FCW alert scenarios fit the following criteria:

- V2V-equipped RV is within range
- Equipped RV is traveling in the same direction as the TRP bus (RV heading angle within ±5 degrees of TRP bus heading)

[7] The IE cannot conclude definitively if an alert should have been issued in a given driving scenario because it does not have access to the proprietary warning logic implemented by the manufacturer.

- Range from V2V data is within ±10 m of the range from forward radar data (to identify scenarios where the TRP bus is following a lead vehicle that may be the V2V-equipped vehicle within range)
- TRP bus speed >6.3 m/s (minimum observed speed of FCW warning)
- TRP bus instantaneous deceleration > 0.25g while time-to-collision (TTC)[8] to RV is < = 5 s
- No FCW or EEBL alerts are triggered during the event

The IE analyzed the video data from each scenario to validate that the lead RV was V2V-equipped, then compared the vehicle dynamics of the TRP bus and the lead vehicle to the vehicle dynamics observed in the FCW scenarios.

2.1.2.2 CSW

The IE identified potential missed CSW alerts using an algorithm that identified events when TRP buses approached or traversed one of the two equipped curves above the CSW threshold speed (more than 10 mph over the posted speed limit), and an alert was not issued. The IE selected curves in the missed alert algorithm based on the locations that CSW alerts were observed in the dataset.

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

- TRP bus is entering or traversing:
  - The Bonisteel Boulevard equipped curve at a speed over 35 mph
  - The Plymouth Road equipped curve at a speed over 45 mph
- Speed remains over threshold speed for over 1 second
- No CSW alerts are triggered during the event

The IE then analyzed the video to determine the location of the TRP bus within the curve when the speed was above the CSW threshold.

2.1.2.3 VTRW

The IE identified potential missed VTRW alerts using an algorithm that identified scenarios where the TRP bus was stopped at a VTRW-enabled bus stop, was passed by a V2V- equipped vehicle in the adjacent lane, and a VTRW was not issued.

Potential missed VTRW alert scenarios fit the following criteria:

- TRP bus is located at one of the VTRW enabled bus stops
- TRP bus is stopped
- TRP bus brake pedal is not engaged (because VTRW alerts are suppressed if the brake is engaged)
- V2V-equipped remote vehicle is within range

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[8] TTC represents the number of seconds until the TRP bus would come into contact with the RV, and is calculated with the following equation: (range to lead vehicle/closing speed to lead vehicle).

- Equipped RV is traveling in the same direction as the TRP bus (RV heading angle within ±5 degrees of TRP bus heading)
- RV comes within 4 m of TRP bus (to identify adjacent lane vehicles)

The IE then analyzed the video to determine the path of the RV and whether or not it approached from behind the TRP bus or from the adjacent lane.

2.2 Results

System performance results are broken down by safety application.

2.2.1 FCW

This subsection presents system performance results and missed alert analysis results for the FCW safety application.

2.2.1.1 FCW Alert Classifications

The intent of the FCW application is to warn drivers of slower moving or stopped vehicles in their path of travel. Figure 2-3 shows the forward target location of the 588 analyzed FCW alerts. The results show the percentage of alerts in each category. The numbers on top of the bars represent the total number of alerts in each category.

Alerts categorized as “in-lane” (indicated by the blue bar) are considered to be true alerts because they address the intended safety need and the design intent of the application. All other categorizations are considered to be false alerts.[9] Overall, 41 percent of the analyzed FCW alerts were issued for in-lane targets.

Definitions for each forward target location category are listed below:

- *In-path:* Remote vehicle is in the same lane of travel and in the intended path of the TRP bus. Alerts were considered in-path if any part of the remote vehicle was in the TRP bus’ lane at the onset of the alert.
- *One lane over*: Remote vehicle is in the travel lane adjacent to the TRP bus.
- *Left turn lane*: Remote vehicle is one lane over, in the dedicated left turn lane preparing to go left at an intersection.
- *Two or more lanes over*: Remote vehicle is in a same-direction travel lane two or more lanes over from the TRP bus.
- *Vehicles separating*: Remote vehicle is moving away from the TRP bus (traveling faster) in either the same lane, or the lane adjacent to the TRP bus.
- *Behind:* Remote vehicle is directly behind or traveling adjacent to the TRP bus.
- *Other*: The remote vehicle is off the roadway, or the remote vehicle is not positioned appropriately for an FCW alert (e.g., in an adjacent parking lot, on a perpendicular roadway, or traveling in the opposite direction).

[9] With the exception of the category “other” the correct classification of alerts in this category could not be confirmed.

- *Unsure:* More than one remote vehicle was in front of the bus when the alert was issued, and it could not be confirmed which vehicle was the V2V-equipped vehicle (the remote vehicle could either be in-path, in an adjacent lane, or two or more lanes over).

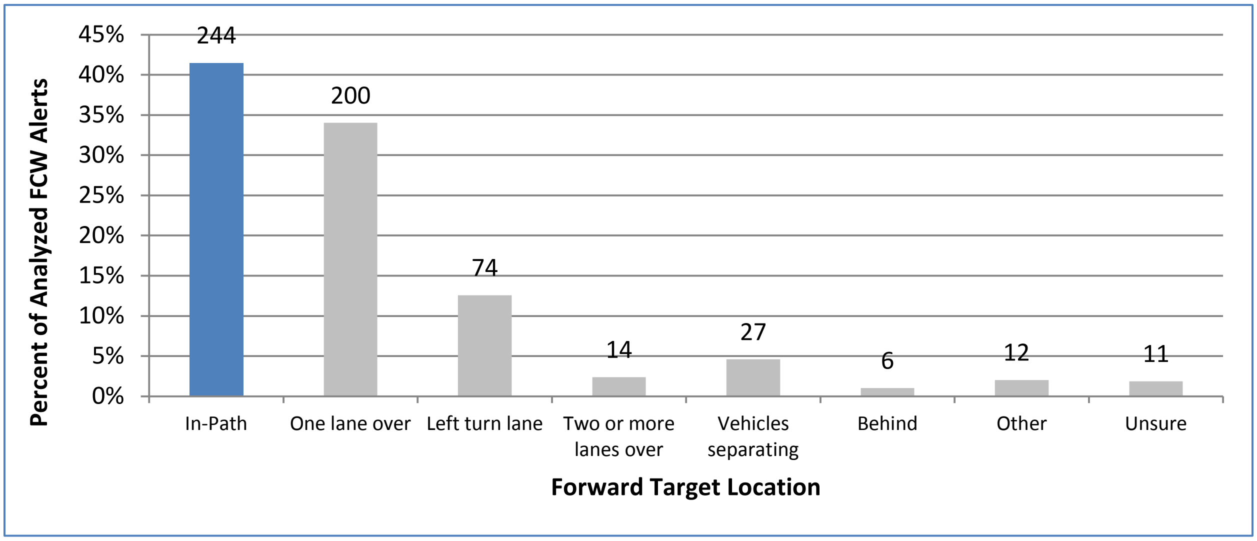

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Figure 2-3. FCW Target Location

Of the 244 alerts that were issued for in-lane remote vehicles, 49 (20 percent) were issued when the driver was already braking. Because the driver is already responding to the threat when the alert is issued, drivers often consider these alerts to be nuisance alerts. A total of 195 alerts (33 percent of all analyzed FCW alerts) were issued for in-lane targets when the driver had not yet braked in response to the threat.

In the following subsections, FCW target locations are broken down by remote vehicle motion (stopped or moving), road curvature, and target device type. In these analyses the “out-of-path” category includes one lane over, left turn lane, and two or more lane over targets; while “Other” includes vehicles separating, behind, other, and unsure.

2.2.1.2 Remote Vehicle Motion

To assess the impact of the remote vehicle dynamics on alert performance, the FCW performance data were broken down by remote vehicle motion.

Figure 2-4 shows the breakdown of remote vehicles for stopped targets and moving targets. The percentage of alerts issued for in-path targets was about twice as high for moving targets (53 percent) than for stopped targets (23 percent).

One explanation for the difference in performance between stopped or moving targets is that alerts issued for stopped targets were issued from further away from the target than for moving targets. Alerts issued for stopped targets were issued from an average range of 36.7 m while alerts issued for moving targets were issued from an average range of 32.3 m. From a further range, it is more difficult for the system to determine the lane position of a remote vehicle.

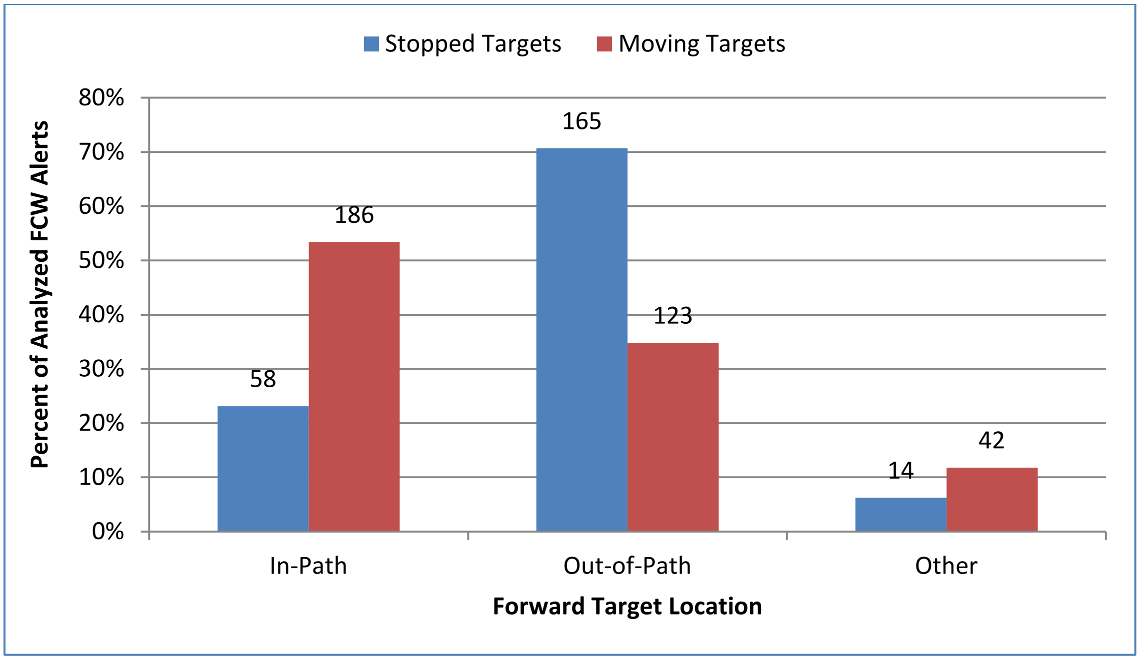

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Figure 2-4. FCW Target Location by Remote Vehicle Motion

2.2.1.3 Road Curvature

To understand the impact of road curvature on FCW application performance, the data were broken down by whether or not the remote vehicle was traversing a curved road segment at the time of the alert.[10] Road curvature can create difficulties in determining lane-level accuracy since targets that are in-lane on a curved road may appear to be out-of-path to the FCW application.

Figure 2-5 shows the breakdown of FCW target location by phase and road curvature. The percentage of alerts issued on curved roads that were in-path was higher for curved roads than for straight roads. This is an unexpected finding, as it is generally more difficult for an FCW application to properly place a lead target when in a curve (see Section 2.2.1.5).

[10] 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).

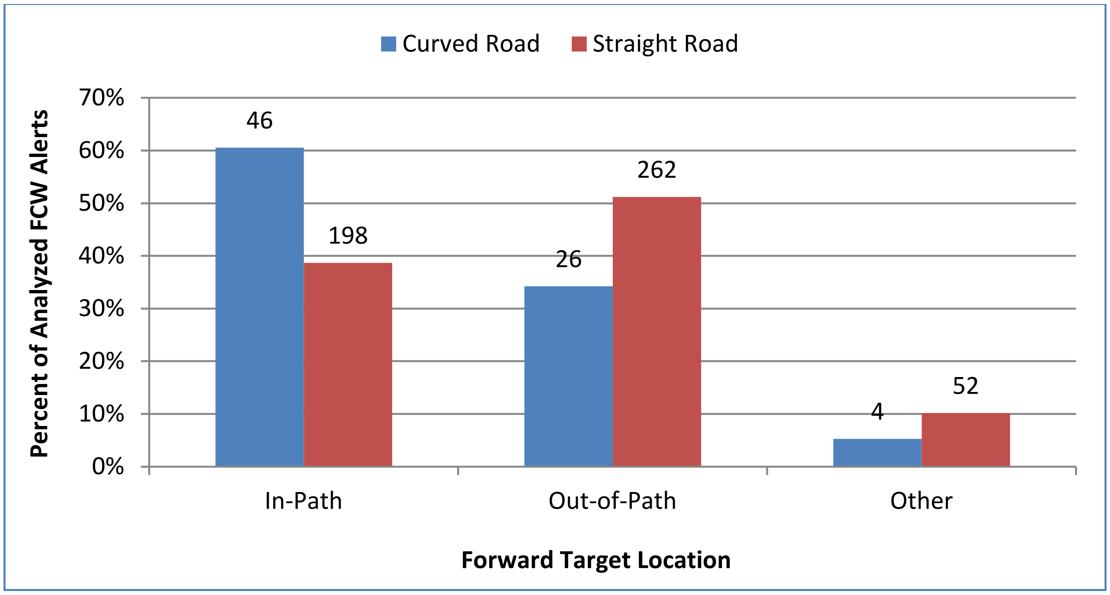

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Figure 2-5. FCW Target Position by Road Curvature

2.2.1.4 Target Device Type

Finally, FCW target position was broken down by the target device type. The ability of a safety application to issue alerts appropriately depends on the accuracy and quality of the data it is receiving from the remote vehicle. If a remote vehicle is broadcasting incorrect, incomplete, or untimely information, it can trigger false alerts in surrounding vehicles. A variety of DSRC devices, antenna types, and antenna mounting locations, were implemented in the Model Deployment environment, all of which could impact the quality of the data and equipped vehicle transmits.

Figure 2-6 breaks down the remote vehicle location data of 588 analyzed FCW alerts with by the target device type and remote vehicle location. Forty-one percent of the FCW alerts issued to TRP buses were triggered by other buses; 14 percent by other TRP buses and 27 percent by University of Michigan buses with VADs. This is likely due to driving patterns and to the high concentration of buses that frequenlty travel the major bus routes. Additionally, many FCW alerts were observed when the TRP buses were approaching other buses stopped at bus stops, providing many opportunities for FCW alerts.

While the percentage of alerts issued for in-path targets for VAD targets (both VAD-equipped buses and VAD-equipped passenger cars) is similar to the overall in-path percentage (42 percent), the percentage of in-path alerts issued for other TRP buses was 60 percent. These performance differences were likely due to travel patterns. All three TRP-equipped buses traveled primarily on commuter routes that passed through the pedestrian detection-equipped intersection, meaning that it was common for two TRP buses to be traveling the same route. When traveling the same route, buses generally use the same lane and stop at the same bus stops, which creates many opportunities for in-path FCW alerts to be issued, and fewer opportunities for false (out-of-path) alerts.

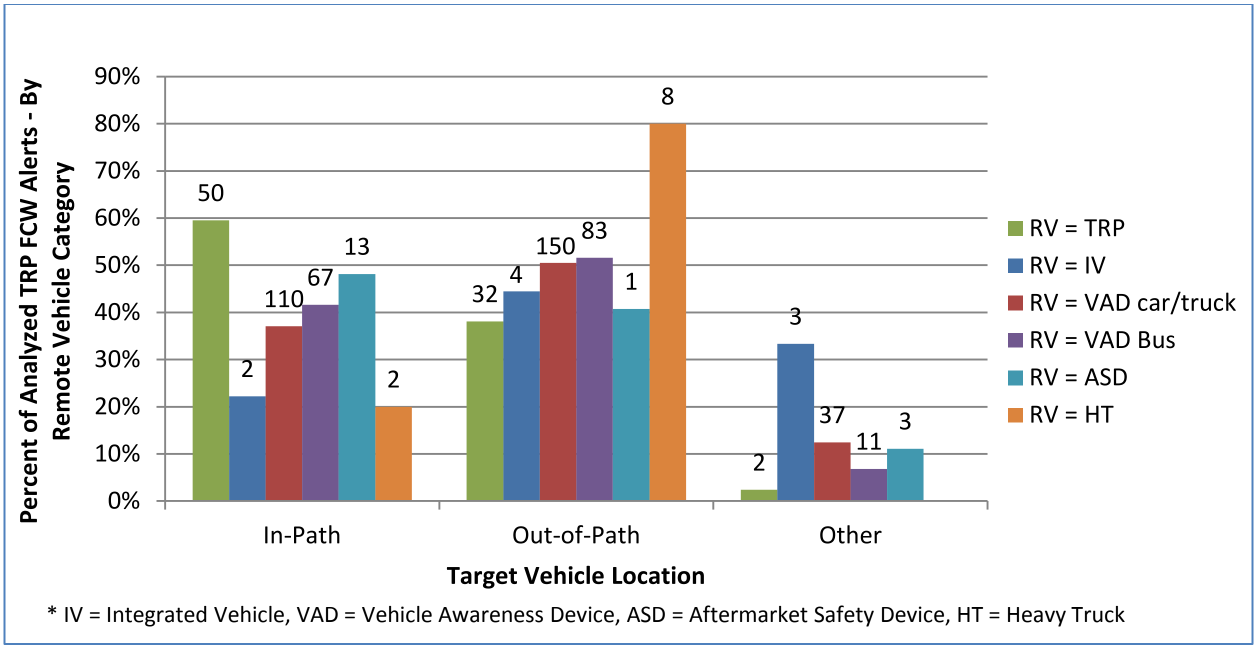

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Figure 2-6. Remote Vehicle Location Broken Down by Target Device Type

2.2.1.5 FCW Missed Alerts

Using the algorithm described in Section 1.1.2.1 and video validation of the results, four events were identified as potential missed FCW alert scenarios. The vehicle dynamics for each of the four scenarios were compared to the vehicle dynamics of observed FCW alerts to confirm that the scenarios were similar. The events were broken down by the lead vehicle motion, since the alert timing and vehicle dynamics in FCW scenarios is different, depending on whether the target is stopped or decelerating. One of the potential missed FCW alerts had a stopped target (called a lead vehicle stopped, or LVS alert) and the other three had targets that were decelerating (called a lead vehicle decelerating or LVD alert).

Figure 2-7 compares the host vehicle speed (descending from left to right) and TTC for LVS alerts against potential missed FCW scenarios with a stopped target[11]. The blue diamonds represent the TTC and speed of the TRP bus at the time of the FCW alert onset, for the LVS alerts observed in the Model Deployment. The green line is a data trace of the potential missed LVS alert scenario. Moving from left to right in the chart, as the TRP bus slows down, the TTC to the lead vehicle also decreases. The data trace passes through the cluster of blue diamonds, indicating that the vehicle dynamics during the potential missed alert scenario were within the TTC and speed range of the observed alerts. This suggests that the warning criteria were met, and an alert should have been issued.

Figure 2-8 shows host vehicle speed versus TTC at the onset of observed LVD alerts, as well as the TTC verses speed trajectory for the three potential missed FCW alerts with decelerating targets. As in Figure 2-7,

[11] FCW timing is dependent on TTC, and varies with vehicle speed, so vehicle speed verses TTC is a common way to represent the performance of an FCW system. TTC at the time of the FCW alert is a metric used to assess the appropriateness of the alert timing (whether alerts are issued too early, at the right time, or too late).

the blue diamonds represent the speed of the TRP bus and the TTC to the lead vehicle at the time of the observed LVD alerts issued in the Model Deployment. The three lines represent the potential missed alert scenarios. Moving from left to right in the chart, in each of the scenarios the TTC to the lead vehicle decreases as the TRP bus slows down (speed decreases).

Figure 2-9 shows the same events but compares time headway to speed (since scenarios with decelerating targets 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 show that the TTC and speed of all three potential missed alert scenarios were within the range of the TTC and speed of the observed alerts, suggesting that alerts should have been issued in these scenarios.

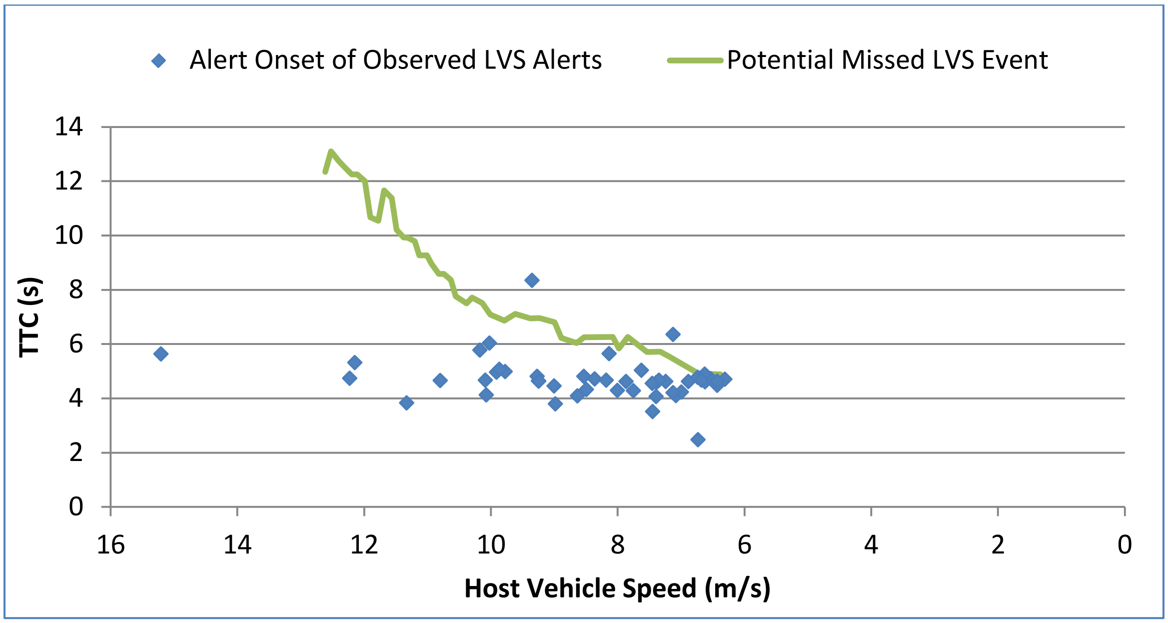

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Figure 2-7. Comparison of TTC for FCW Alert and Potential Missed FCW Alerts with Stopped Targets

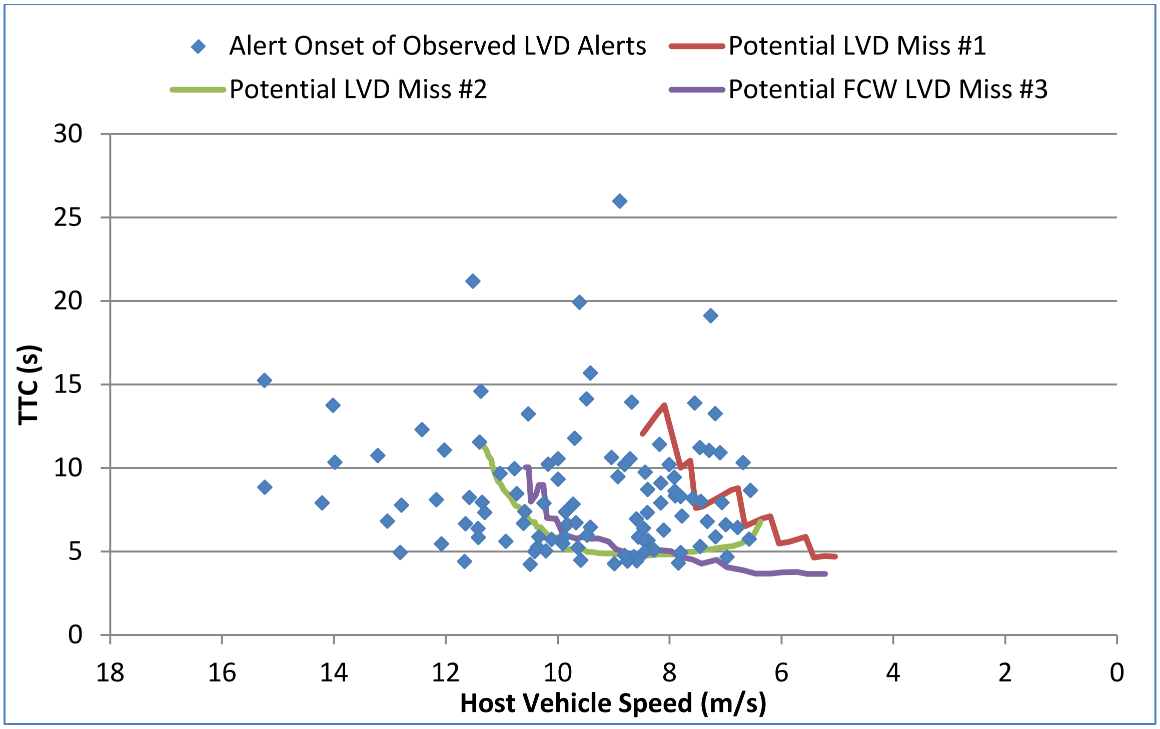

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Figure 2-8. Comparison of TTC for FCW Alert and Potential Missed FCW Alerts with Decelerating Targets

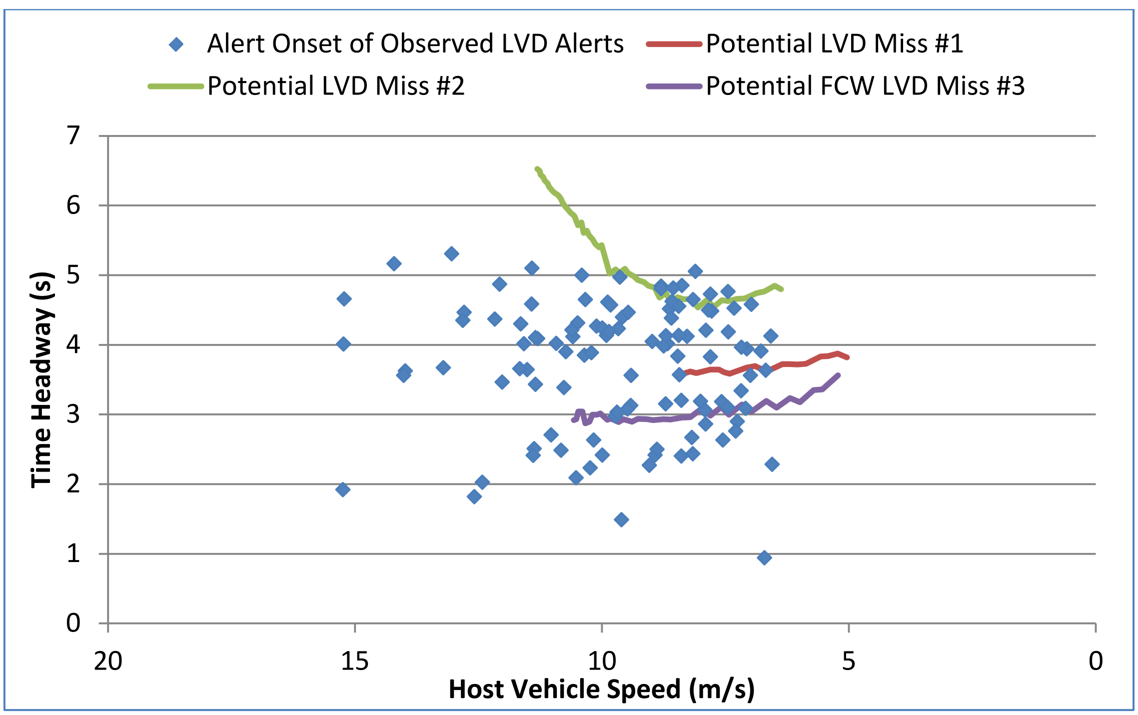

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Figure 2-9. Comparison of Time Headway for FCW Alert and Potential Missed FCW Alerts with Decelerating Targets

All three of the potential missed FCW events with decelerating targets occurred when the host vehicle was traversing a medium-radius curve (ranging from 120 m to 195 m). When in a curve, it is more difficult for the safety application to determine the lane position of the lead vehicle. Therefore, it is possible that the road geometry was a factor in the alert not being issued.

2.2.2 CSW

This subsection presents system performance results and missed alerts analysis for the CSW safety application.

2.2.2.1 CSW Classifications

Since the CSW application is designed to issue a warning to a driver if s/he is traveling too fast while entering a sharp curve, CSW alerts are classified by the location of the TRP bus within the curve and the TRP bus speed at the time of the alert. There are four host vehicle location categories:

- *Curve entry:* The alert was issued as the TRP-equipped bus approached the equipped curve.
- *In-curve:* The alert was issued as the TRP bus was traversing the curve.
- *Curve exit:* The alert was issued after the TRP bus passed the apex of the curve.
- *Not at equipped curve:* The alert was not issued at a CSW-equipped curve.

Figure 2-10 shows the location of the bus within the curve for the 519 CSW alerts that were analyzed. Alerts in the first two categories—Curve Entry and In-Curve (indicated in blue)—are considered true alerts because they are issued early enough so that the driver can slow down before reaching the apex of the curve. Fifty-seven percent of the alerts analyzed fell into one of these two categories. Thirty-seven percent of CSW alerts were issued at the curve exit. These alerts were considered to be false since the information was no longer useful to the driver after they have traversed the curve (alert is issued late). Alerts that were not issued at an equipped curve (7 percent) were also false alerts.

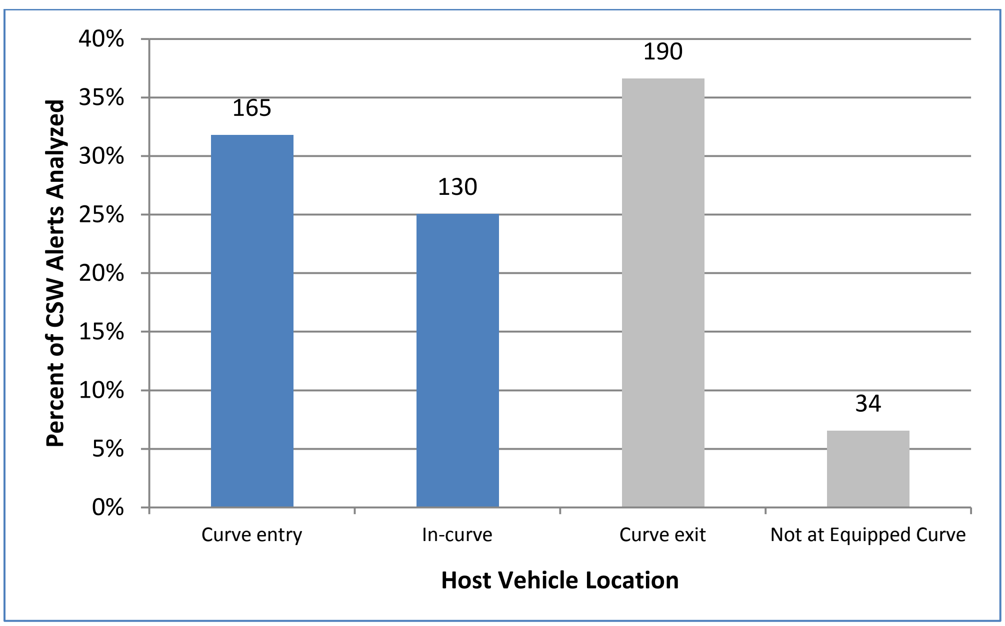

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Figure 2-10. Host Vehicle Location within Curve at Curve Speed Warning Onset

Of the 485 CSW alerts that were issued on equipped curves, only 7 (less than 2 percent) were issued when the TRP bus was traveling below the threshold speed for the given curve. Three of the 7 events were issued when the bus was stopped, and the speed of the other four events ranged from 10 to 20 mph under the alert speed threshold.

2.2.2.1.1 Host Vehicle Location by TRP Travel Direction

Of the 485 CSW alerts issued on equipped curves 481 were issued on Bonisteel Boulevard, and four were issued on Plymouth Road.[12] The 481 alerts issued on Bonisteel Boulevard were broken down by curve direction, to determine if the performance was impacted by the direction in which the bus approached the curve.

Figure 2-11 shows the Bonisteel Boulevard CSW-equipped curve, which is a divided roadway. When a bus approaches the curve from the south it will make a right hand turn around the curve, and when it approaches from the east it will make a left-hand turn around the curve.

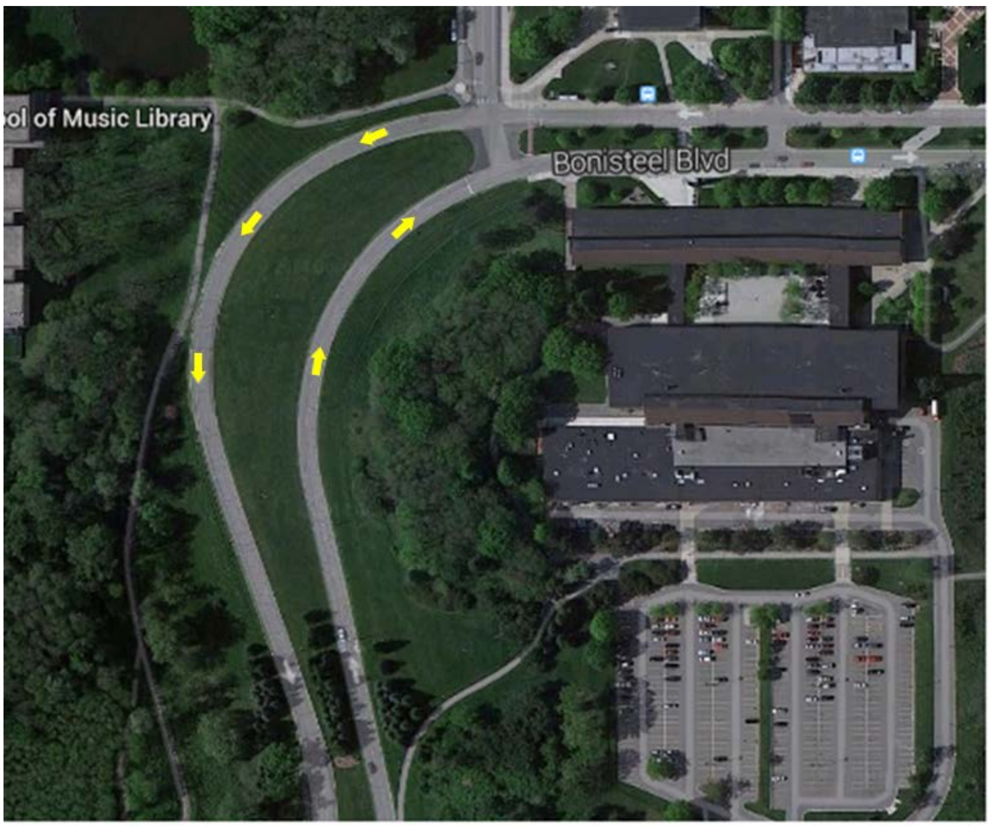

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Figure 2-11. Bonisteel Boulevard CSW-Equipped Curve

The host vehicle location varied considerably depending on whether the bus was approaching the equipped curve from the south (turning to the right) or from the east (turning to the left). Figure 2-12 shows the

[12] Host vehicle location for Plymouth Road CSW Alerts: Curve entry = 1, In-curve = 1, Curve exit = 2

breakdown of host vehicle locations for left and right traverses through the Bonisteel Boulevard-equipped curve. While 100 percent of the alerts when the TRP was approaching the equipped curve from the south were issued either in the curve entry or in the curve (true alerts), only 36 percent of the alerts issued when the bus approached from the east were true alerts. This is possibly due to the speed profile of the bus when approaching/navigating the curve; the approach from the east has a stop sign 15 m before the curve entry, whereas the approach from the south is located over 200 m away from an intersection. When approaching from the east the bus approaches the curve from a stop and would therefore be less likely to exceed the speed threshold required to trigger a CSW alert until later in the curve. When approaching from the south the bus arrives at the curve entry already traveling at-speed, and would be more likely to already be traveling above the CSW threshold when entering the curve.

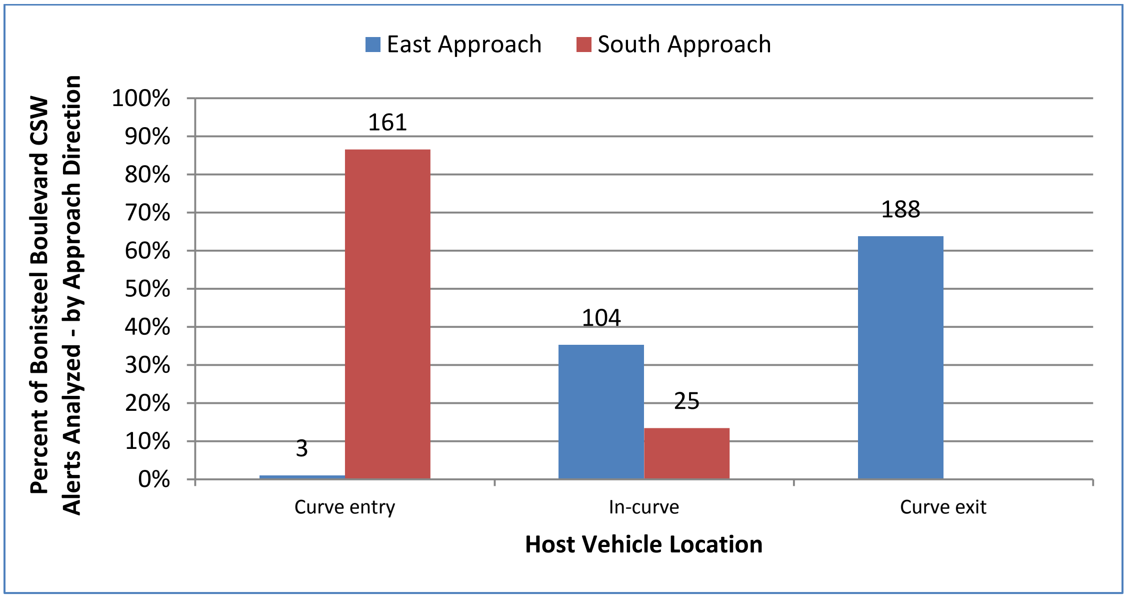

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Figure 2-12. Host Vehicle Location within Curve at CSW Onset – By Turn Direction

2.2.2.2 CSW Missed Alerts

Using the algorithm described in Section 2.1.2.2 and video validation of the results, there were 22 scenarios where the TRP bus traversed an equipped curve while traveling above the threshold speed for over 1 second, but did not receive a CSW alert. The video validation process included identifying where in the curve the bus first exceeded the threshold speed, and identifying scenarios where the threshold speed was reached during the curve entry, or while the bus was in the curve. In 5 of the 22 potential missed alert events (23 percent) the bus first exceeded the threshold speed at the curve entry. In the other 17 cases (77 percent) the bus exceeded the threshold speed while traversing the curve. All 22 potential missed CSW events occurred on the equipped curve on Bonisteel Road. Ninety-three percent of all CSW alerts analyzed also occurred at this curve.Volpe

Figure 2-13 shows the breakdown of the 22 potential missed CSW alerts by approach direction. Similar to with the false alerts, the CSW safety application performed more accurately when the TRP was approaching the curve from the south; 15 of the 22 potential missed alerts were in scenarios where the TRP approached from the east, while only 5 were in scenarios where the TRP approached from the south.

Missed CSW alerts could be caused by either application logic or infrastructure availability.

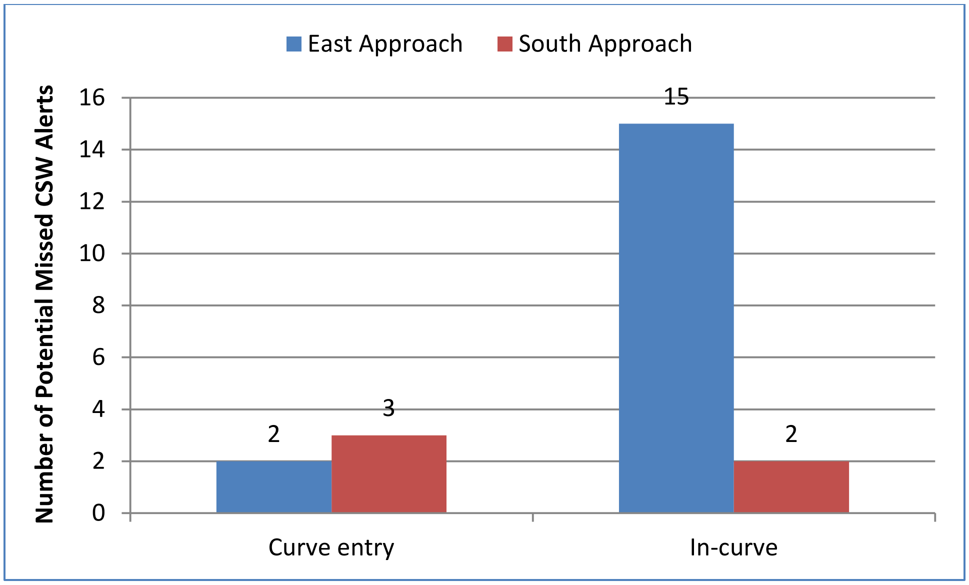

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Figure 2-13. Breakdown of Potential Missed CSW Alerts, by Host Vehicle Location and Approach direction

2.2.3 EEBL

The EEBL application is designed to issue a warning when a vehicle ahead (either in the same lane as the host vehicle or in an adjacent lane) is decelerating quickly. EEBL warning accuracy was analyzed based on the location of the remote vehicle and whether or not that vehicle was decelerating.

Figure 2-14 shows the target location for the 27 EEBL alerts. Since the EEBL application issues alerts for remote vehicles ahead in both the same lane and in lanes adjacent to the host vehicle, the category “ahead” refers to any remote vehicle that is ahead on the same road as the host vehicle. Twenty-five EEBL alerts (93 percent) were issued for remote vehicles on the same road as the host vehicle (represented by the blue bar in Figure 2-14). Two EEBL alerts (7 percent) were issued for vehicles on adjacent roads. These alerts were not a potential threat to the host vehicle and were therefore considered to be false.

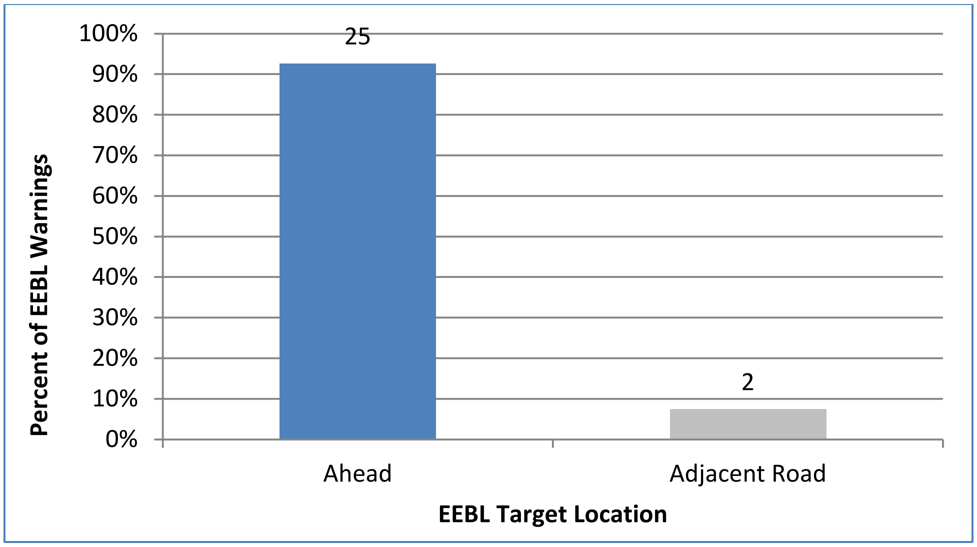

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Figure 2-14. Host Vehicle Location within Curve at Curve Speed Warning Onset

In all 25 EEBL alerts the remote vehicle was decelerating at the time the alert was issued.

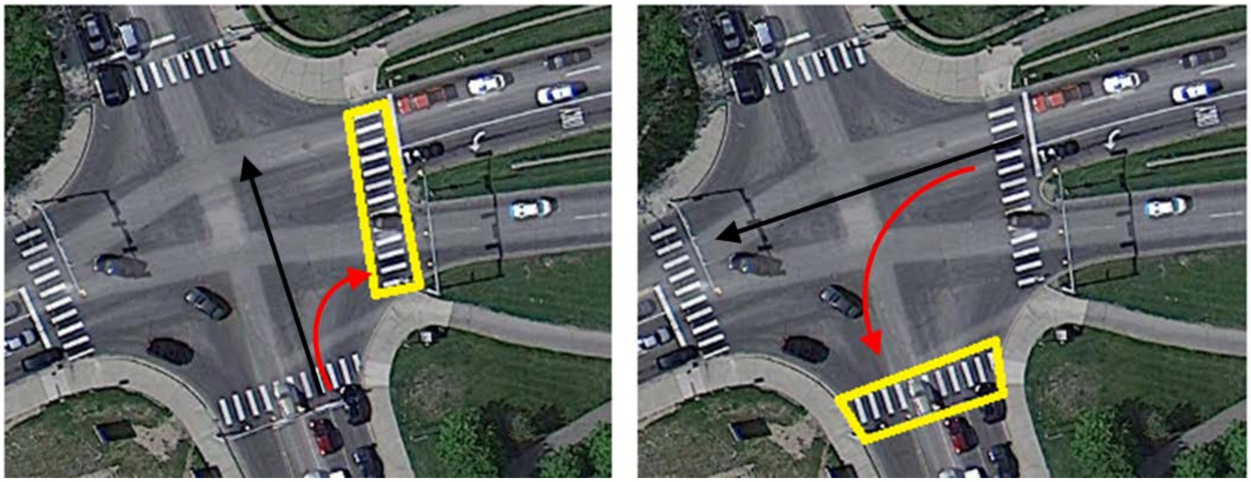
Thirteen EEBL alerts were triggered by VAD-equipped University of Michigan buses, eleven EEBL alerts were triggered by VAD-equipped cars or trucks, while the remaining 3 were triggered by ASD equipped vehicles. Both of the false EEBL alerts were triggered by VAD-equipped remote vehicles.

2.2.4 Pedestrian Crash Warning

This subsection presents system performance results for the PCW application. The results from the Model Deployment and Redeployment test periods are presented separately, since changes were made to improve the PCW application performance prior to the Redeployment test period.

2.2.4.1 Classification Criteria

The PCW application is designed to alert the TRP bus driver if a pedestrian is present when the bus is about to turn through one of the pedestrian detection-equipped crosswalks. Figure 2-15 shows the geometry of the PCW-equipped intersection. In the left image the target crosswalk for the right turn warnings is highlighted in yellow. In the right image the target crosswalk for the left turn warnings is highlighted in yellow. The red arrow shows the path of the bus that the PCW application is designed to address; the bus will turn either right or left then traverse the target crosswalk. The black arrows illustrate an alternate path, in which the bus goes straight through the intersection and does not cross the equipped crosswalk. Warnings should not be issued when the bus does not traverse the equipped crosswalk.



TRP bus right turn across equipped crosswalk **TRP bus left turn across equipped crosswalk**

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Figure 2-15. Intersection Geometry and Equipped Crosswalks for the PCW Application

The performance of the PCW application is classified based on whether or not the bus traversed the equipped crosswalk and on the presence of a pedestrian in the crosswalk at the time of the alert.

- *Bus traverses crosswalk*: Describes whether or not the bus followed the intended path through the equipped crosswalk.
  - *Yes:* The bus turned and traveled through the pedestrian detection-equipped crosswalk (red arrows in Figure 2-14).
  - *No*: The bus continued straight through the intersection and did not cross through the crosswalk (black arrows in Figure 2-14).
- *Pedestrian in crosswalk*: Describes whether or not a pedestrian is present in the equipped crosswalk at the time of the alert.
  - *Yes:* A pedestrian is seen in the crosswalk.
  - *No:* The crosswalk is visible in the video but no pedestrian is in the crosswalk.
  - *Unsure:* The video does not allow confirmation of whether or not a pedestrian is present (either because the bus is too far away from the intersection to have a view of the crosswalk or because the video view is obstructed).

In addition to evaluating the accuracy based on the above classification variables, the alerts are broken down by the location and movement of the bus relative to the crosswalk at the time of the alert. While this element was not integrated into the design of the application, it is relevant to application performance because the timing of the alert and the location of the bus when the driver receives the alert will impact whether or not it is helpful to the driver. The criteria for assessing bus position are described below; the first three categories contain alerts that are potentially helpful to the driver, while the last three categories are likely to be perceived as nuisance alerts:

- *Approaching green light:* The bus is approaching the equipped intersection and the light is green, allowing the bus to proceed through the cross walk.
- *Stopped – first in queue*: The bus is stopped at a red light and is first in the traffic queue, then will proceed through the crosswalk when the light turns green.
- *Turning*: The bus is proceeding through the intersection.
- *Approaching red light:* The bus is approaching the intersection, preparing to stop at the red light.
- *Stopped – second or more in queue*: The bus is stopped in the traffic queue, waiting to proceed into the intersection.
- *In-Past Crosswalk*: The bus is crossing through—or has already passed the crosswalk—at the time of the alert (late alert).

2.2.4.2 Model Deployment Classification Results

Table 2-3 shows the breakdown of the 435 analyzed PCWs based on the design criteria. The application was designed to issue warnings when the bus was approaching an equipped crosswalk and a pedestrian was present. The dark grey cell in Table 2-3 represents scenarios that satisfy these criteria. Twenty-nine alerts satisfied the design criteria. The pale blue cells represent false alerts; 256 alerts were false alerts either because the bus did not traverse the equipped crosswalk or there were no pedestrians in the crosswalk. In 150 events, the bus traversed the crosswalk, but the presence of a pedestrian could not be confirmed (represented by the pale grey cell[13]).

When considering only the alerts where the presence of a pedestrian could be confirmed (248), 12 percent satisfied the warning criteria and 88 percent did not.

Table 2-3. Breakdown of Model Deployment PCWs Based on Design Criteria

		Pedestrian in Crosswalk		
		Yes	**No**	**Unsure**
Bus Path Through Crosswalk	**Yes**	29	167	150
	No	0	52	37

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Figure 2-16 shows the 29 alerts that satisfied the warning criteria broken down by the location and maneuver of the bus at the time of the alert. The blue bars represent the alert categories that are potentially helpful to the driver.

Seventy-two percent (21) of the 29 PCWs that satisfied the warning criteria were issued in scenarios that were potentially helpful to the drivers. Overall, when considering only the alerts where the presence of a pedestrian could be confirmed, 8 percent of the PCW alerts were issued for scenarios that satisfied the warning criteria, and could potentially help the driver avoid hitting a pedestrian.

[13] These alerts could be either true or false alerts.

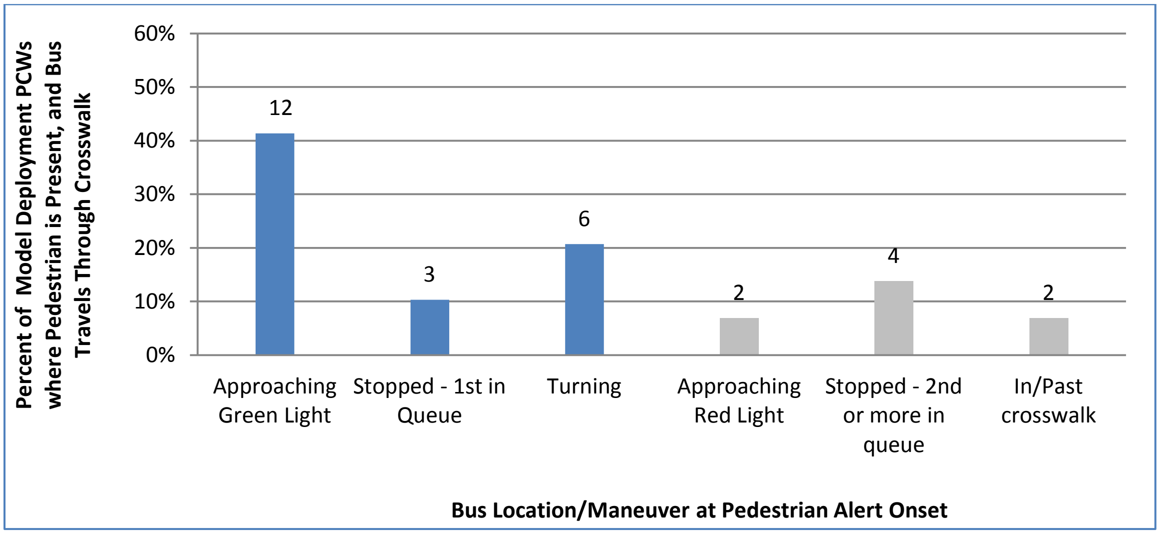

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Figure 2-16. Bus Location/Maneuver at Time of Pedestrian Alert – Model Deployment

2.2.4.3 Redeployment Classification Results

Seventy PCWs were issued during the redeployment of the TRP applications. Table 2-4 shows the breakdown of these events. Similar to the analysis of PCW alerts from the Model Deployment test period in Table 2-3 the dark grey cell in Table 2-4 represents events that satisfy warning criteria (8 alerts), pale blue cells represent false alerts (29 alerts), and the grey cell represents alert scenarios where the presence of a pedestrian could not be determined (33 alerts).[14]

When considering only the alerts where the presence of a pedestrian could be confirmed (33), 24 percent met the warning criteria and 76 percent did not.

Table 2-4. Breakdown of Redeployment PCWs Based on Design Criteria

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Pedestrian in Crosswalk</td></tr>
<tr><td>Yes</td><td>No</td><td>Unsure</td></tr>
<tr><td rowspan="2">Bus Path Through Crosswalk</td><td>Yes</td><td>8</td><td>23</td><td>33</td></tr>
<tr><td>No</td><td>0</td><td>2</td><td>4</td></tr>
</table>

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[14] These events could be either true or false.

Figure 2-17 shows the 8 PCW events that satisfied the warning criteria broken down by the location and maneuver of the bus at the time of the alert. The blue bars represent the alert categories that are potentially helpful to the driver.

Six of 8 events were issued in driving scenarios where the alert could potentially be helpful to the driver. Overall, when considering only the alerts where the presence of a pedestrian could be confirmed, 18 percent of the PCW alerts during the Redeployment phase were issued for scenarios that satisfied the warning criteria, and could potentially help the driver avoid hitting a pedestrian. It is important to note that the software changes made prior to the Redeployment included adjusting the geographic window in which the alerts could be issued, to prevent alerts from being issued when the bus was already in or past the crosswalk (late alerts). There were no late alerts observed during the Redeployment.

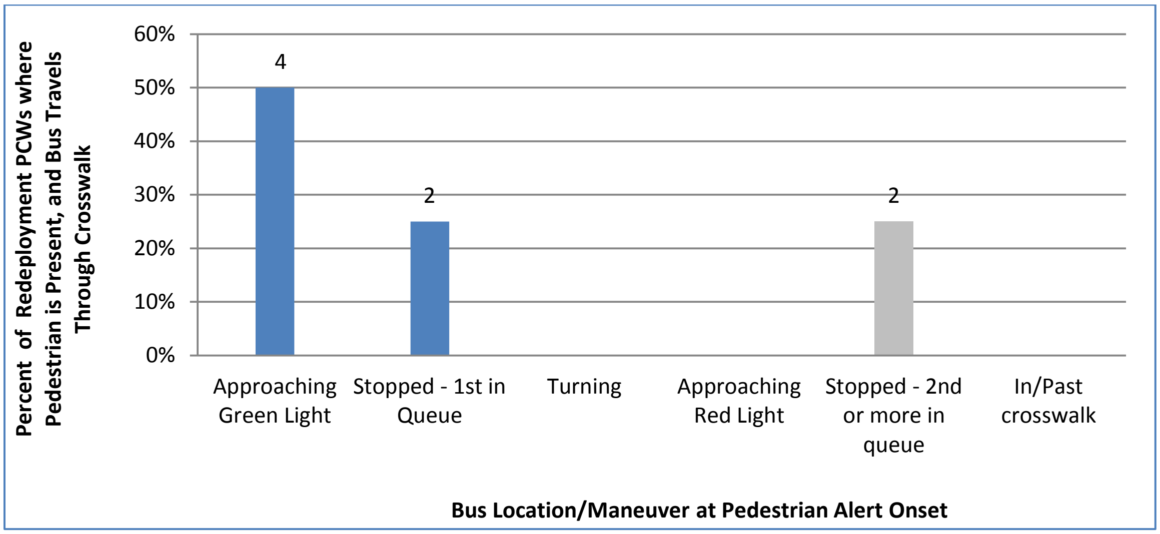

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Figure 2-17. Bus Location/Maneuver at Time of Pedestrian Alert – Redeployment

2.2.4.4 Model Deployment and Redeployment Classification Comparison

Figure 2-18 compares the performance of the PCW application during the Model Deployment and Redeployment test periods. This analysis includes only events where the presence of the pedestrian could be confirmed (only events where pedestrian presence could be confirmed were included in this analysis). In this comparison the category “valid” refers to alerts that satisfy the warning criteria of the application (bus traverses the equipped crosswalk and a pedestrian was present). The percentage of valid alerts more than doubled from 12 percent during Model Deployment, to the 24 percent during Redeployment.

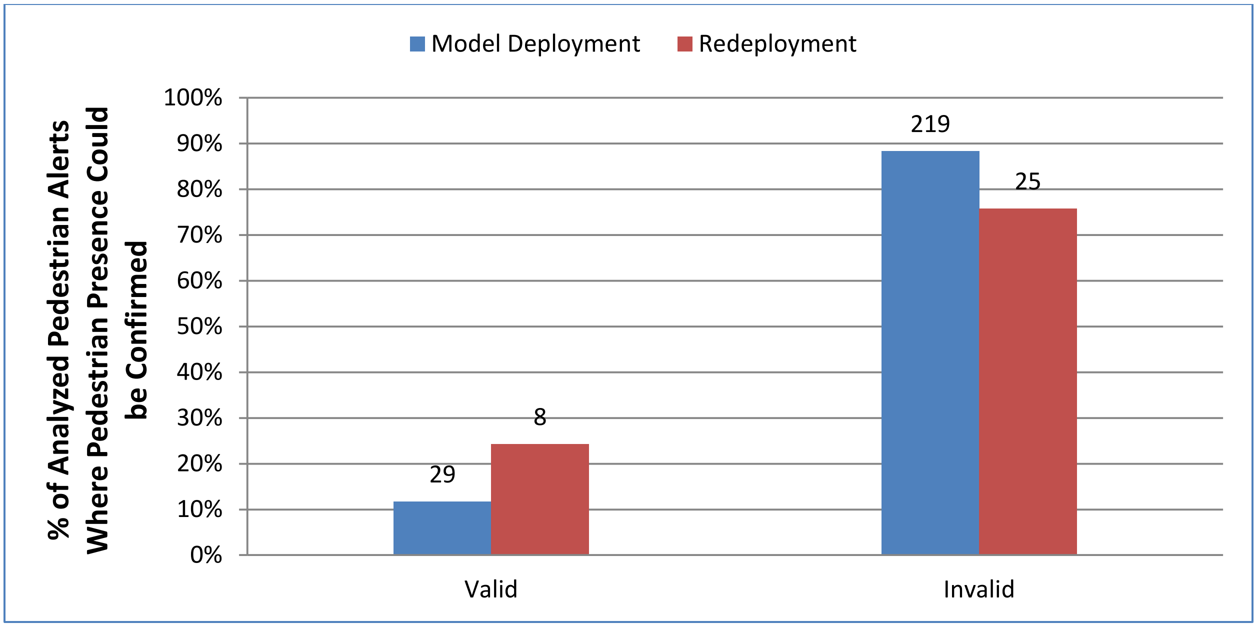

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Figure 2-18. PCW Performance by Test Period

When considering the path of the bus independently, the performance of the bus traversing the crosswalk improved from 80 percent of intersection traverses during Model Deployment to 91 percent of intersection traverses during Redeployment.

2.2.5 VTRW

This subsection presents system performance results missed alert results for the VTRW application. The results from the Model Deployment and Redeployment test periods are presented separately, since software changes were made to improve the VTRW prior to the Redeployment

2.2.5.1 VTRW Classifications

The VTRW is designed to let the bus driver know if another vehicle is attempting to turn in front of the bus when the bus departs from a bus stop.[15] There are two levels of alerts: 1) the cautionary or inform alert (yellow) warning lets the bus driver know that another vehicle has moved from directly behind the bus to the side of the bus, and 2) the imminent (red) warning lets the driver know that a vehicle has moved from directly behind the bus to the adjacent lane, and is initiating a maneuver to re-enter the lane in front of the bus or to turn right in front of the bus. These alert scenarios are illustrated by arrows in their respective colors in Figure 2-19.

[15] Only designated bus stops are enabled for the VTRW application. The application is enabled when the TRP bus enters the geographic area of a designated bus stop.

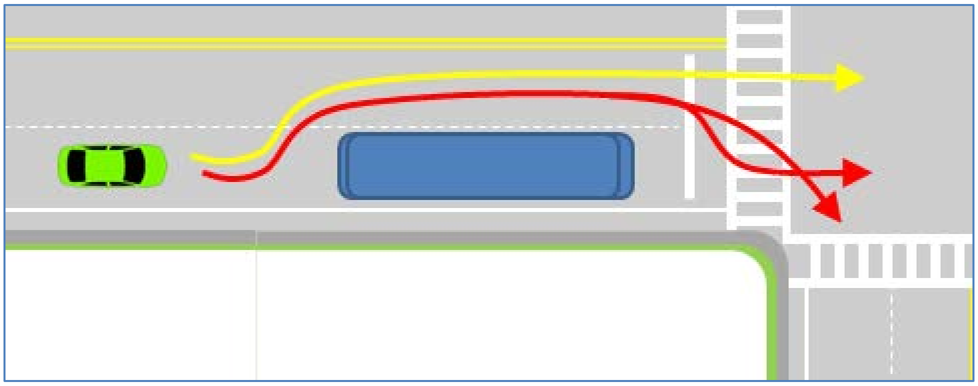

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Figure 2-19. Intended Path of RV Travel for Cautionary and Imminent VTRW

The VTRW accuracy was assessed based on whether or not the remote vehicle followed the path specified in the warning criteria. More details about the VTRW design criteria are in the Transit Safety Retrofit Package Development Test Report [2].

This evaluation also addressed the intention of the TRP driver at the time the alerts are issued. The IE observed that some VTRW alerts were issued when the driver was parked or not otherwise intending to proceed from the bus stop (e.g., the bus is parked and the driver is reading or doing paperwork). These alerts were likely to be perceived as nuisance alerts by the driver. While this scenario was not addressed in the design of the application during the Model Deployment, software changes were made prior to the Redeployment that disabled the VTRW when the TRP bus transmission was in park.

2.2.5.2 Model Deployment Classification Results

Fifty-one cautionary and 18 imminent VTRWs were analyzed from the Model Deployment test period. Figure 2-20 shows the breakdown of these warnings by the path of travel of the RV. The RV followed the prescribed path in 14 percent of the cautionary alerts and in 22 percent of the imminent warnings. Alerts issued when the RV did not follow the prescribed path are considered to be false alerts.

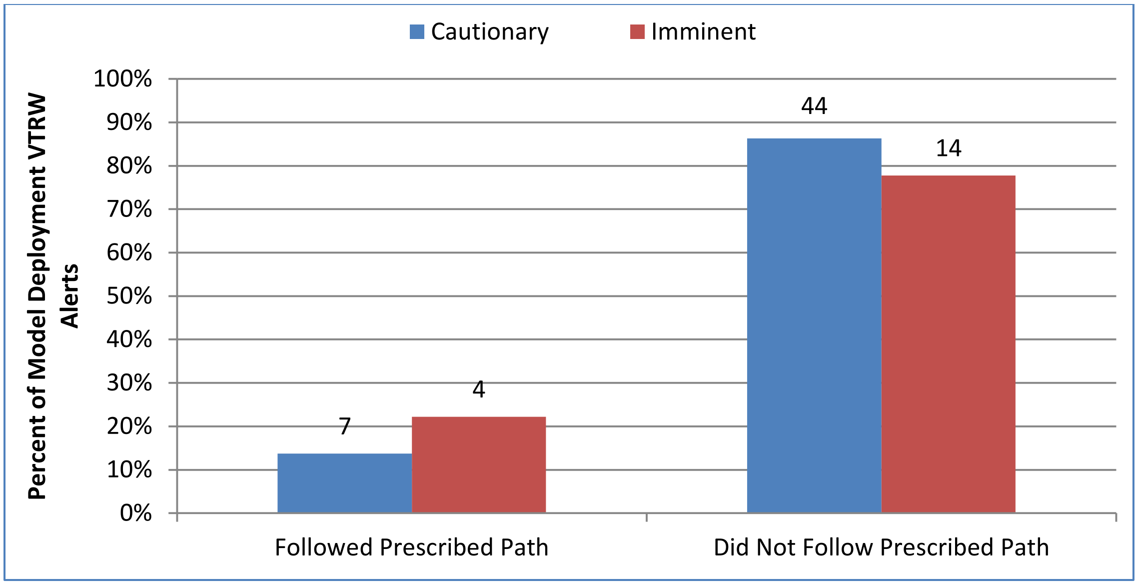

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Figure 2-20. Model Deployment VTRWs by RV Path of Travel

Figure 2-21 breaks down the 58 false VTRW alerts from the Model Deployment by type of false alert.Thirty-six percent of the false RVTW alerts (cautionary and imminent combined) were considered false because the RV approached from the adjacent lane rather than from directly behind the bus. Over half (52 percent) of the false alerts were classified false because the RV was still behind the bus when the alert was issued. Forty-three percent of the false imminent VTRW alerts were considered false because even though the RV started from behind the bus and moved into the adjacent lane, it did not turn in front of the bus (these events would have been valid cautionary warnings but did not satisfy the criteria for an imminent warning). In the one remaining alert (cautionary) the RV was stopped in front of the TRP bus (and had been for some time) when the alert was issued.

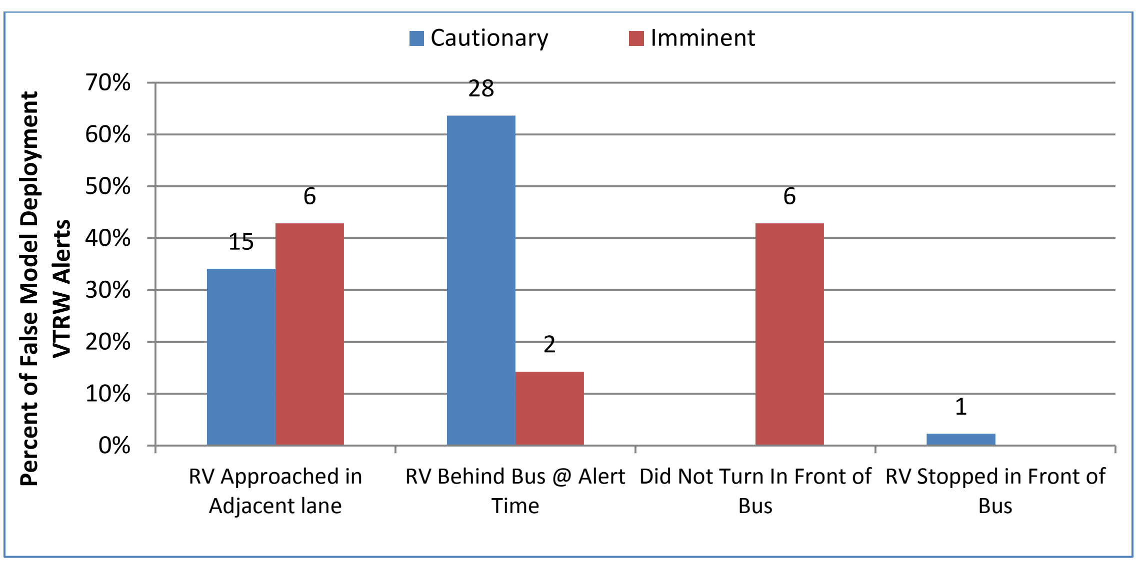

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Figure 2-21. Breakdown of False VTRWs from Model Deployment

2.2.5.2.1 Driver Intent to Proceed

Each VTRW alert was examined based on the bus driver's intent to proceed from the bus stop when the alert was issued. If the driver was not attempting to depart from the bus stop when the alert was issued, it is unlikely that the information provided by the alert would be helpful.

During the Model Deployment:

- Twenty-five of 51 cautionary VTRW alerts (49 percent) were issued when the bus driver was intending to depart the bus stop.
- Six of the 18 imminent VTRW alerts (33 percent) were issued when the bus driver was intending to depart the bus stop.

Of the 11 Model Deployment VTRW alerts where the target followed the prescribed path (Figure 2-20), two were issued when the driver intended to proceed (both cautionary). Overall, four percent of Model Deployment VTRW cautionary alerts were issued in scenarios that met the design criteria and could potentially help the driver avoid hitting a right turning vehicle. None of the VTRW imminent alerts were issued in scenarios that met the design criteria and could potentially help the driver avoid hitting a right turning vehicle.

2.2.5.2.2 Remote Vehicle Device Type

During the Model Deployment test period:

- Ninety-three percent of VTRWs were triggered by other University of Michigan transit vehicles (89 percent VAD-equipped buses, and 4 percent TRP buses). This is probably because there is extensive bus traffic at the VTRW-enabled bus stops, with many buses using the bus stops simultaneously. Four percent of VTRWs were triggered by car/truck VADs, one percent by ASDs, and one percent by Integrated Light Vehicles.
- Five of the cautionary VTRWs that followed the prescribed path were triggered by VAD-equipped buses and the other two were triggered by TRP buses.
- All four imminent VTRW alerts that followed the prescribed path were triggered by VAD-equipped buses.

2.2.5.3 Redeployment Classification Results

Of the 7 VTRW alerts issued during the Redeployment five were cautionary and two were imminent. None of the alerts followed the prescribed path for their given alert type.

Figure 2-22 shows the breakdown of these events by false alert type. Four of the alerts were false because the alert was issued when the RV was still behind the bus. Three of the alerts were false because the RV approached from two lanes over rather than from directly behind the bus.

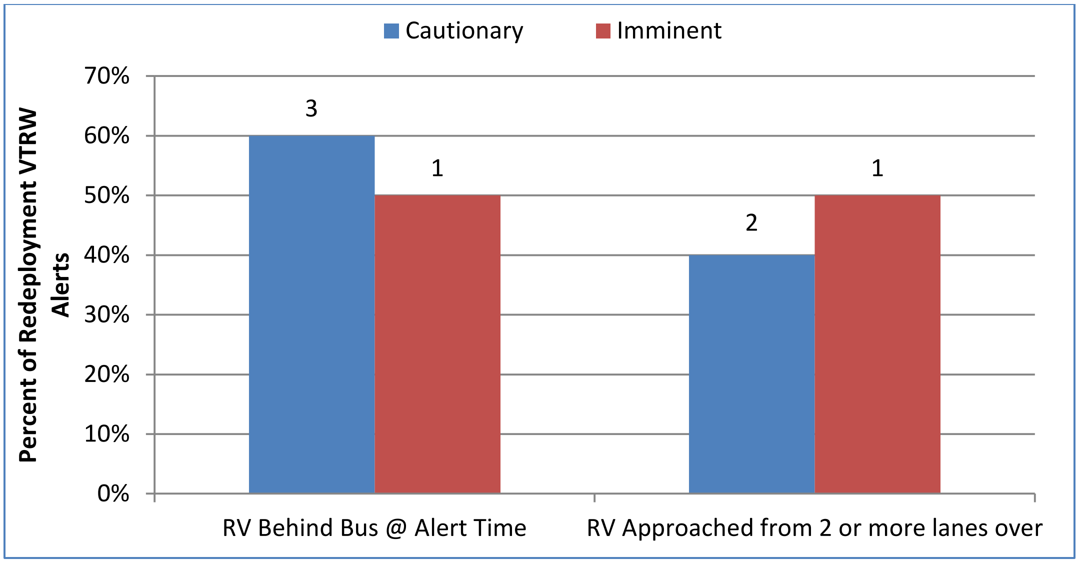

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Figure 2-22. Breakdown of False VTRWs from Redeployment

2.2.5.3.1 Driver Intent to Proceed

To reduce the number of VTRW alerts issued when the bus was parked, software changes were made that only allowed VTRWs to be issued when the bus transmission was in drive. As a result, during the Redeployment:

- Four of 5 cautionary VTRW alerts (80 percent) were issued when the bus driver was intending to depart the bus stop.
- Both of the imminent VTRW alerts (100 percent) were issued when the bus driver was intending to depart the bus stop.

2.2.5.3.2 Remote Vehicle Device Type

During the Redeployment test period, five alerts were triggered by VAD-equipped transit buses, and two were triggered by other VAD-equipped vehicles. The IE did not observe any differences in accuracy by remote vehicle device type.

2.2.5.4 Missed VTRW Alerts

The algorithm described in Section 2.1.2.3 and video validation identified two events that are potentially missed VTRW scenarios. In both of these events, the equipped RV approached the bus from behind, then moved into the adjacent lane, and traversed around the bus. However, in both events the driver had the brake engaged for most of the event, and then released the brake when the remote vehicle was toward the front of the bus. It is possible that a VTRW alert would have been issued earlier when the brake was engaged, but was suppressed by the alert logic (by design, the VTRW does not issue alerts if the brake pedal is engaged).

3 Safety Impact

The safety impact analysis addressed two primary areas;

1. *Driver response to safety application alerts* addressed how the alerts impact TRP driver behavior
2. *Driver attention* explored the potential for alerts to have negative unintended consequences

3.1 Technical Approach

This subsection describes the technical approach used to analyze TRP driver responses to alerts and explores the impact of alerts on driver attention.

Since the TRP data collected during the Model Deployment field test do not distinguish between individual drivers, the IE conducted the safety impact analysis across all drivers.

3.1.1 Response to Alerts

This part of the analysis investigated how TRP drivers responded to true safety alerts. In general, drivers are unlikely to respond to alerts when a threat is not present (false alerts) so false alerts were not included in the analysis.[16]

Table 3-1 shows the metrics used to measure driver response for each safety application. These metrics were selected based on the relevant vehicle dynamics for each safety application alert scenario. Section 3.2.1 describes each metric in more detail.

Table 3-1. Driver Behavior Metrics by Safety Application

Safety Application	Driver Response Metrics	Units
FCW	Brake reaction time (to alert)	Seconds
FCW	TTC at brake onset	Seconds
FCW	Peak deceleration	m/s^2
FCW	Average deceleration	m/s^2
FCW	Minimum TTC	Seconds
CSW	Brake reaction time (to alert)	Seconds

[16] False alerts can sometimes have a negative impact on the driver by startling them or making them upset. They can also pose a safety threat by making drivers brake or steer unnecessarily. The IE did not observe any instances of unintended consequences caused by false alerts in the Model Deployment field test.

Safety Application	Driver Response Metrics	Units
CSW	Peak longitudinal deceleration	m/s^2
CSW	Average longitudinal deceleration	m/s^2
CSW	Peak lateral acceleration	m/s^2
CSW	Average lateral acceleration	m/s^2
EEBL	Peak deceleration	m/s^2
EEBL	Average deceleration	m/s^2
PCW	Response rate	Number of alerts
VTRW	Response rate	Number of alerts

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As discussed in Section 1.2.1, the FCW, EEBL, and CSW) safety applications were enabled during the Baseline period, but warnings were not issued to the drivers. To understand the impact of the alerts on driver behavior, the IE compared descriptive statistics of the driver behavior metrics between the Baseline (alerts issued in the background) and treatment (auditory and visual alerts issued to the drivers) periods for these applications. Since the position of the driver interface and the visual and auditory warnings were modified prior to the Redeployment test period, the IE analyzed Model Deployment and Redeployment data separately. Changes in driver response to alerts between the Model Deployment and Redeployment test periods suggest that the changes made to the driver interface impacted driver's responses to alerts.

For the PCW and VTRW applications, the IE compared driver responses between the Model Deployment and Redeployment test periods. Changes were made to both the application software (see Section 1.2.3) and the driver interface. Changes in driver behavior between the Model Deployment and Redeployment could be the result of either (or both) of these modifications.

3.1.2 Driver Attention

To determine if driving with DSRC-based safety systems had an impact on driver distraction or attention to the driving task the IE assessed driver attention using video analysis and coding of the driver face and cabin videos in two ways. First, based on secondary tasks (activities performed while driving that do not contribute to the driving task; for example eating, adjusting the radio, or using a cell phone); and second, based on the direction of the driver's attention (whether or not the driver's attention is on the driving task). Metrics were collected for each of the 1,713 alert events analyzed during the system performance analysis.

While it is common in everyday driving for passenger car drivers to engage in secondary tasks, this was not the case for the TRP drivers observed in the Model Deployment field test. Since the safety of passengers depends on the driver of the bus, transit agencies often prohibit drivers from carrying out select secondary tasks. Specifically, the University of Michigan transit vehicle drivers who participated in the field test were prohibited from using cell phones, eating, or drinking during their shift.

Even though the original evaluation plan included a statistical analysis of the frequency of secondary tasks and distraction events—with and without the safety applications—the IE did not observe a sufficient number of secondary task events to conduct this analysis. Given these limitations, the analysis of driver attention includes summary statistics and descriptions of observed events.

3.2 Results

The following subsections present findings from the safety impact analysis of the TRP safety applications based on response to alerts and driver attention.

3.2.1 Response to Alerts

This subsection summarizes the results of driver responses to safety application alerts by safety application and test period.

3.2.1.1 FCW

The analysis of response to FCW alerts includes only in-path (true) FCW alerts where the driver braked in response to the stopped, slower, or slowing remote vehicle. If a driver did not respond to the remote vehicle, then the data for the relevant response metrics were not available.

As described in Section 2.2.1, 244 of the 588 FCW alerts analyzed were issued for in-path targets. In 51 of these events (21 percent) the driver responded prior to the alert being issued (49 executed a braking response and 2 executed a steering response). In 78 of these events (32 percent) the driver did not respond to the alert because the remote vehicle executed a maneuver that made them no longer a threat, such as turning off or changing lanes, or because the event was not severe enough that the driver needed to brake to avoid a crash. The IE used the remaining 115 in-path FCW events for the driver behavior analysis.

Since the vehicle dynamics of an FCW scenario depend on the vehicle dynamics of the remove vehicle, FCW alerts were broken down into two groups; scenarios where the remote vehicle is decelerating, and scenarios where the remote vehicle is either stopped, or at a constant speed. Stopped and constant speed remote vehicle scenarios can be grouped together because in both of these scenarios the closing speed to the lead vehicle is constant (pending the HV driver response), whereas in the remote vehicle decelerating scenario, the closing speed is variable based on the remote vehicle's acceleration. Separating driver response data into these two categories reduces variability in response metrics and provides a clearer picture of potential changes in response metrics. Of the 115 FCW alerts included in the analysis 80 were remote vehicle decelerating events and 35 were remote vehicle stopped/constant speed events.

Figure 3-1 shows the breakdown of the 80 remote vehicle decelerating and 35 remote vehicle stopped/constant speed events by test period.

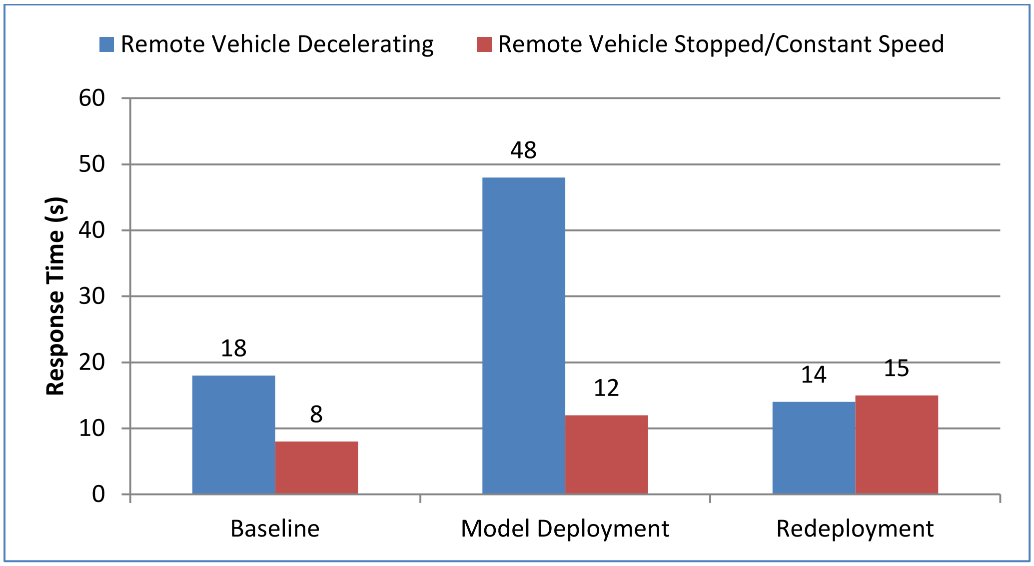

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Figure 3-1. FCW Alerts by FCW Category and Test Period

3.2.1.1.1 Initial Conditions

Figure 3-2 and Figure 3-3 show the host vehicle speed versus TTC at the alert onset for the LVD and 35 LVS/LVM FCW scenarios, respectively[17]. These figures show that the timing and vehicle dynamics of the FCW alerts in each category were consistent throughout the Baseline, Model Deployment, and Redeployment test periods, meaning that changes in driver response to these scenarios would be the result of the safety application warnings being present.

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[17] FCW timing is dependent on TTC, and varies with vehicle speed, so vehicle speed verses TTC is a common way to represent the performance of an FCW system. TTC at the time of the FCW alert is a metric used to assess the appropriateness of the alert timing (whether alerts are issued too early, at the right time, or too late).

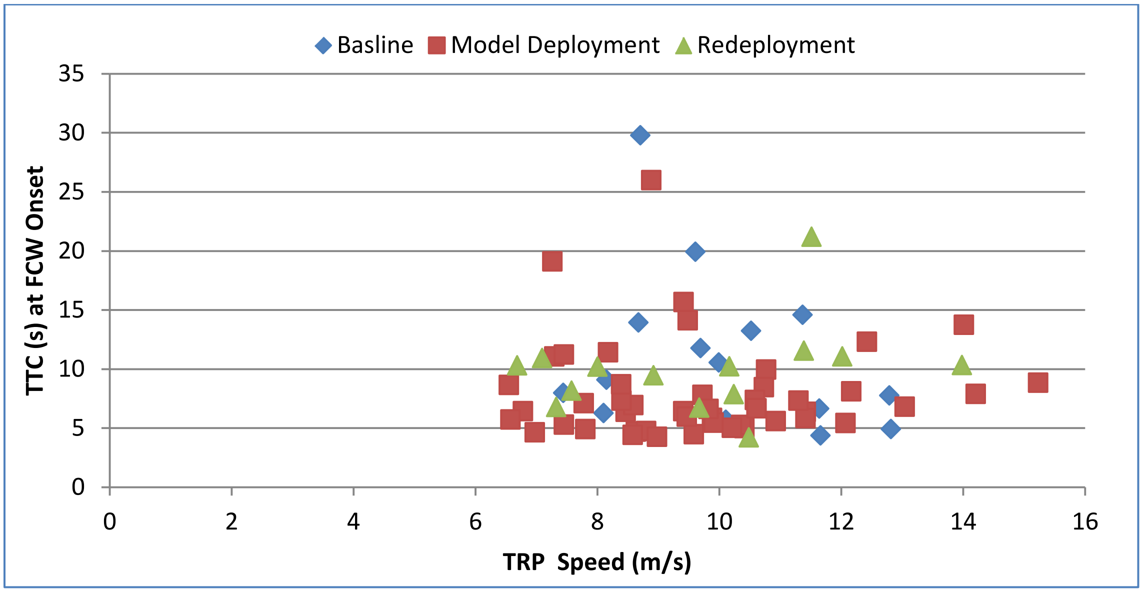

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Figure 3-2. Initial Conditions of LVD FCW Scenarios

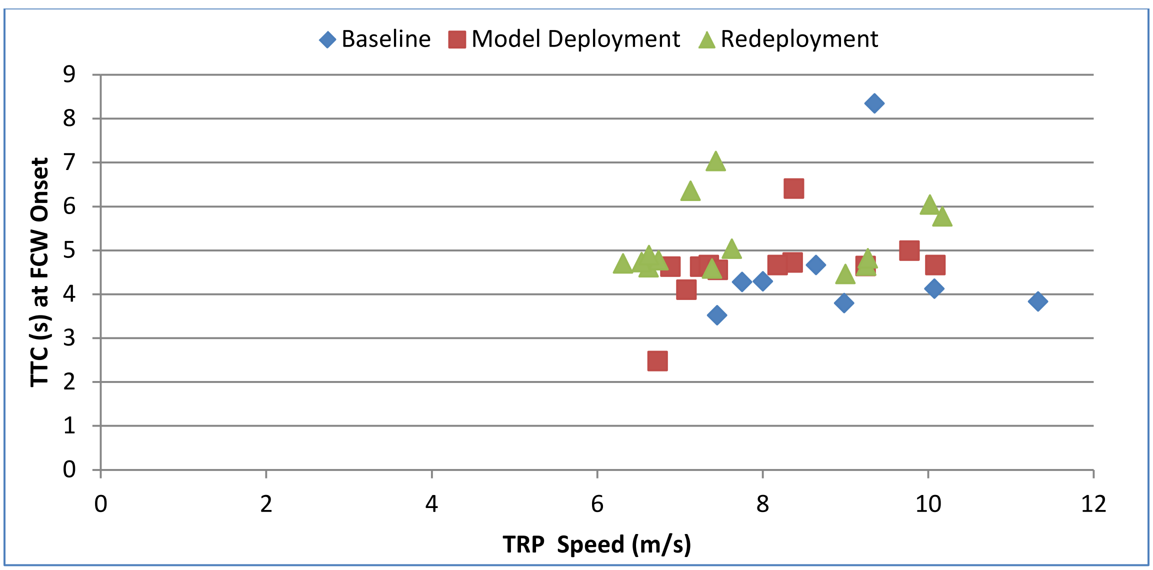

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Figure 3-3. Initial Conditions of LVS/LVM FCW Scenarios

3.2.1.1.2 Response Time

Response time represents the number of seconds between when the alert was issued to the driver (or in the case of the Baseline period, issued silently behind the scenes) and when the driver first engaged the brake pedal. Figure 3-4 shows the mean response time for remote vehicle decelerating FCW alerts in each test period. (For all charts in this section, error bars represent the 95 percent confidence interval.) Figure 3-5 shows the mean response time for remote vehicle stopped/slowing alerts.

For the LVD there was a decrease in mean response time from the Baseline to the Model Deployment and Redeployment test periods (2.26 seconds in Baseline versus 1.45 seconds in Model Deployment and Redeployment combined). This decrease was not statistically significant based on the 95 percent confidence interval. There was also a slight decrease in mean response time for remote vehicle stopped/constant speed scenarios (from 1.63 s to1.19 s). However, the variability in response time during the Baseline period was very large, making it difficult to determine if this change was a trend.

The IE did not observe any differences between response time between the Model Deployment and Redeployment test periods.

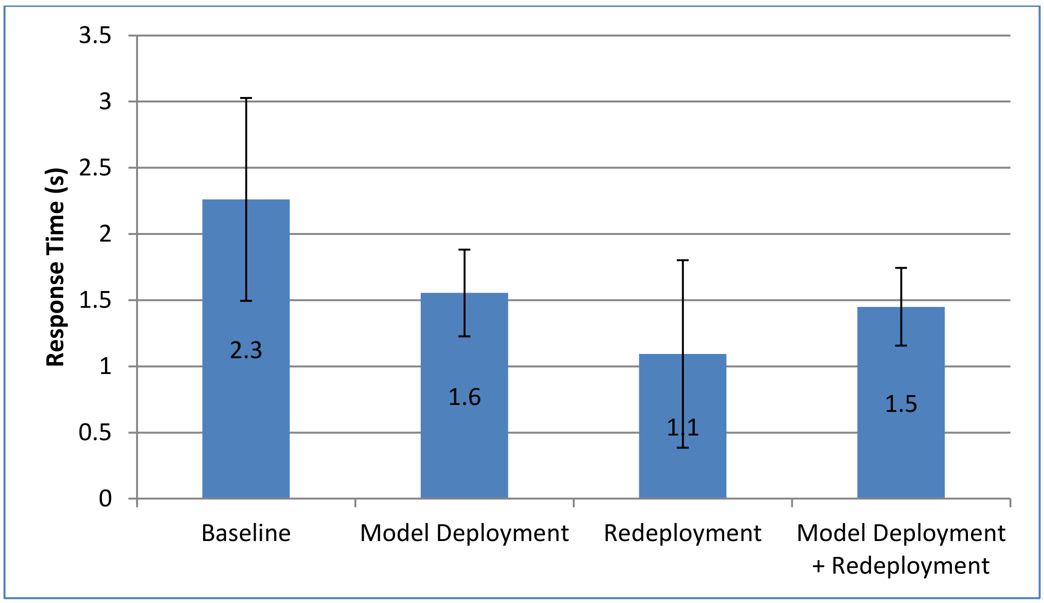

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Figure 3-4. Mean Response Time to LVD FCW Alerts, by Test Period

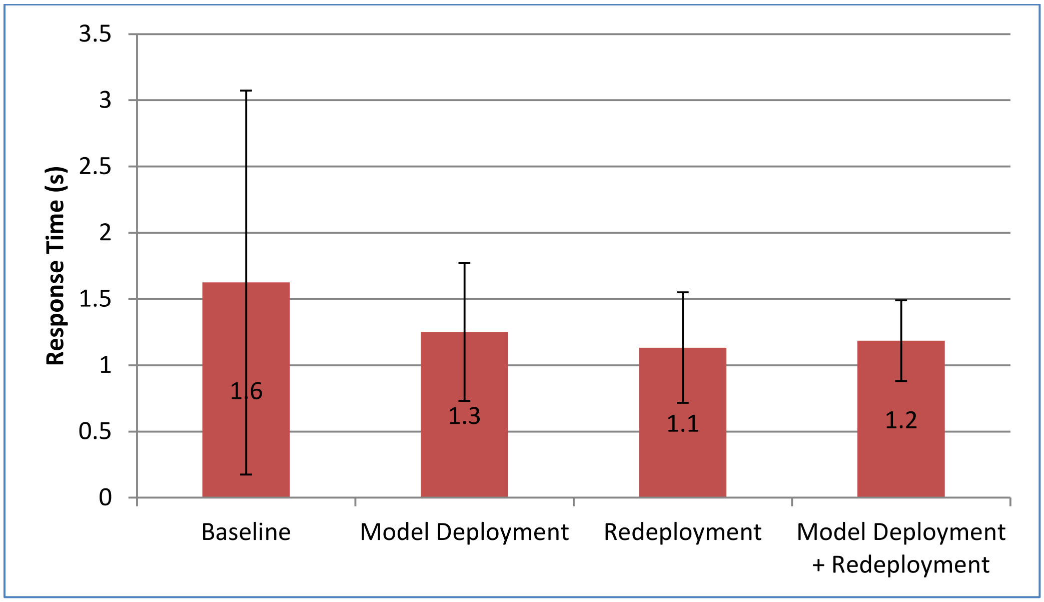

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Figure 3-5. Mean Response Time to LVS/LVM FCW Alerts, by Test Period

3.2.1.1.3 TTC at Brake Onset

TTC at brake onset represents the instantaneous number of seconds until the host vehicle comes into contact with the remote vehicle, at the time the TRP driver responded to the alert. A higher value of TTC at brake onset represents more conservative driving (the driver is braking early); while a lower TTC value represents more aggressive or risky driving (the driver is braking late). Figure 3-6 and Figure 3-7 show the mean TTC at host vehicle brake onset during each test period for the remote vehicle decelerating, and remote vehicle stopped/ constant speed, respectively. The IE did not observe changes in the TTC at brake onset between test periods, meaning that drivers did not brake earlier when FCW alerts were issued.

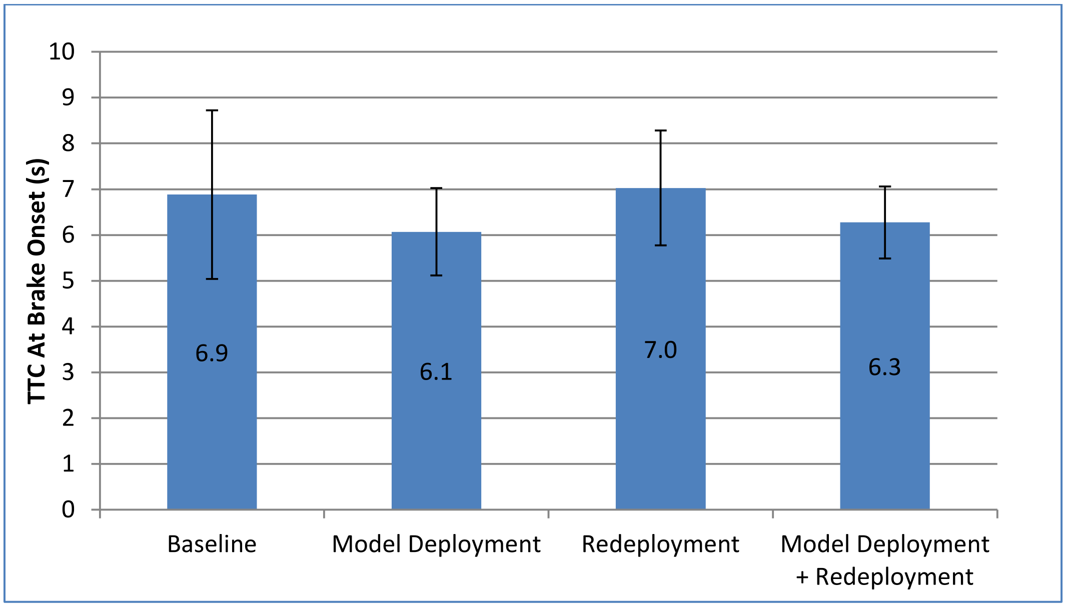

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Figure 3-6. Mean TTC at Host Vehicle Brake Onset for LVD FCW Alerts, by Test Period

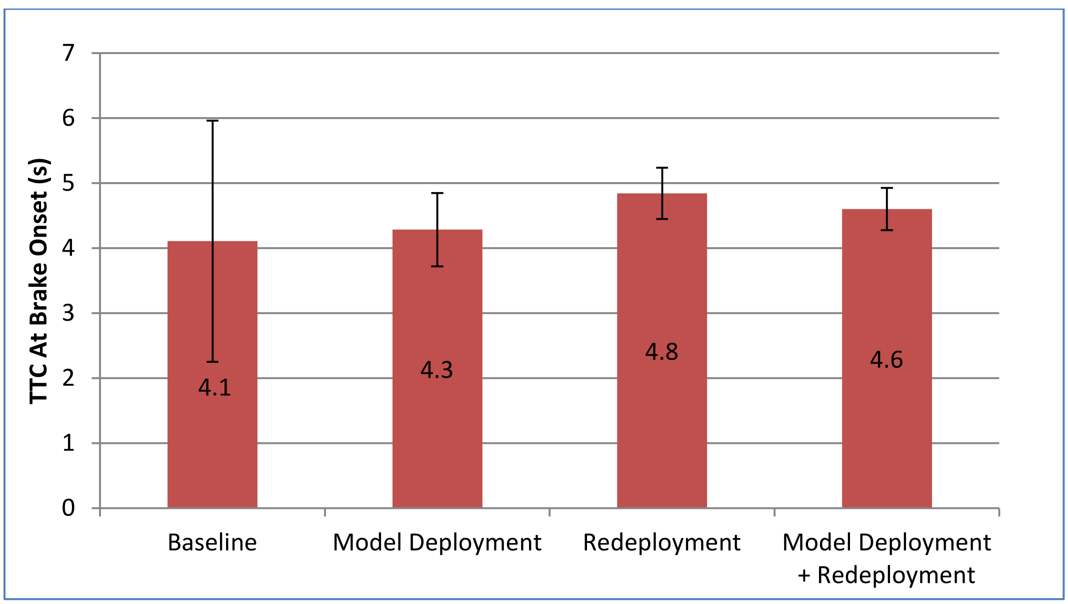

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Figure 3-7. Mean TTC at Host Vehicle Brake Onset for LVS/LVM FCW Alerts, by Test Period

3.2.1.1.4 Peak Deceleration

Peak deceleration represents the highest level of deceleration achieved by the bus during the FCW braking event (or within 5 seconds of the alert onset if the braking event lasted longer than 5 seconds). A higher peak deceleration indicates the driver made a more aggressive braking maneuver. Figure 3-8 and Figure 3-9 show the peak deceleration levels for remote vehicle decelerating and remote vehicle stopped/constant speed FCW events, respectively. The peak deceleration level for remote vehicle decelerating levels ranged from 1.5 to 4.4 m/s^2, with an overall average of 2.4 m/s^2. The peak deceleration level for remote vehicle stopped/constant speed ranged from 1.5 to 3.2 m/s^2 with an overall average of 2.4 m/s^2. The IE considered a braking event with a peak deceleration greater than 3 m/s^2 to be a hard braking event (based on the observed distribution of braking responses). This means that the majority of FCW alerts issued to TRP drivers were not safety critical events that required emergency braking to avoid a crash.

The IE did not observe any changes in the peak deceleration levels between test periods.

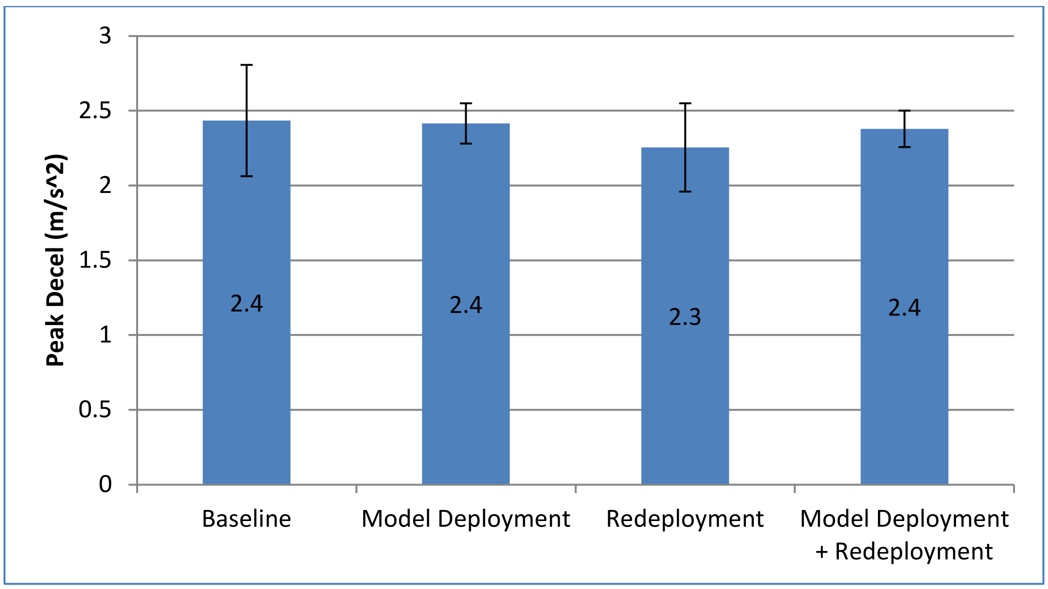

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Figure 3-8. Mean Peak Deceleration for LVD FCW Alerts, by Test Period

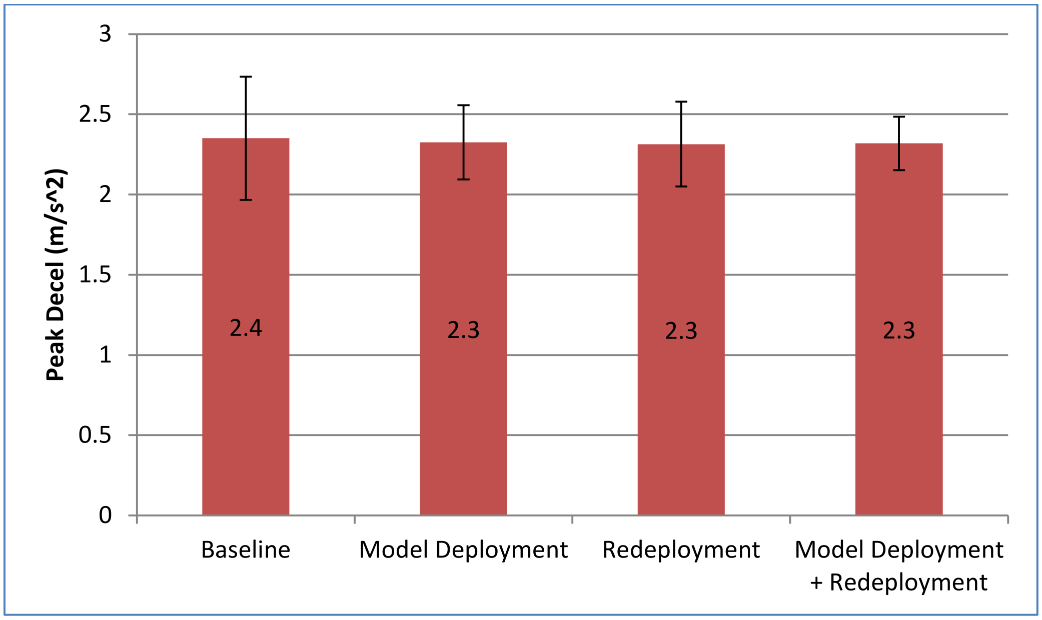

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Figure 3-9. Mean Peak Deceleration for LVS/LVM FCW Alerts, by Test Period

3.2.1.1.5 Mean Deceleration

Like peak deceleration, mean deceleration is a measure of the severity of a braking event. Mean deceleration also takes into account the braking level over the duration of the entire braking event (or within 5 seconds of the alert onset if the braking event lasts longer than 5 seconds). Figure 3-10 and Figure 3-11 show the mean deceleration levels over the course of the braking event for remote vehicle decelerating and remote vehicle stopped/constant speed FCW events, respectively. Similar to the measures for peak deceleration, these results show that braking levels in response to FCW alerts are relatively low in terms of braking severity. Mean deceleration for remote vehicle decelerating scenarios ranged from 0.75 m/s^2 to 2.45 m/s^2 while mean deceleration for remote vehicle stopped/constant speed events ranged from 1.00 m/s^2 to 2.03 m/s^2.

The IE did not observe any changes in the mean deceleration levels between test periods, meaning that drivers did not brake harder when FCW alerts were issued.

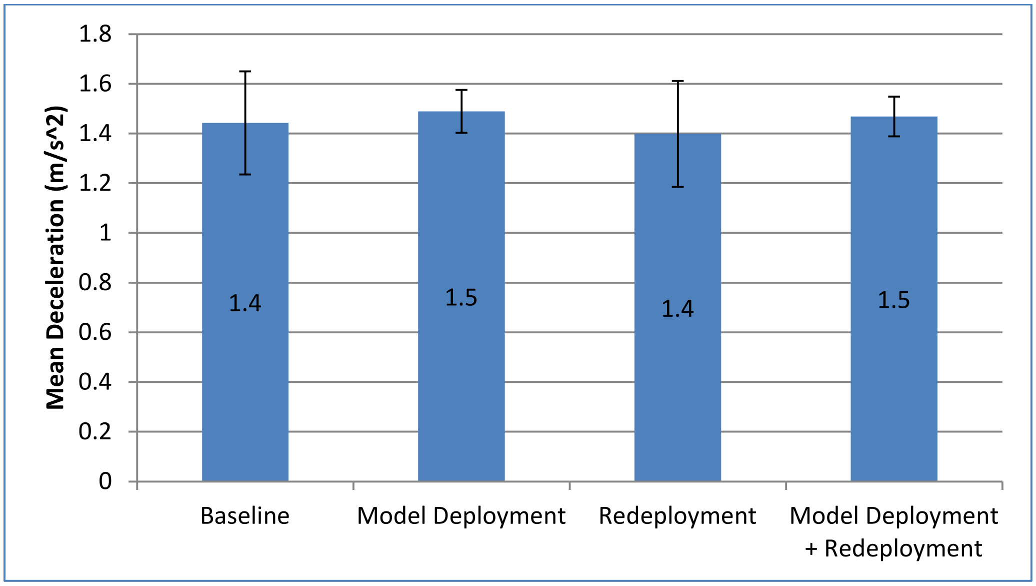

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Figure 3-10. Mean Mean Deceleration for LVS/LVM FCW Alerts, by Test Period

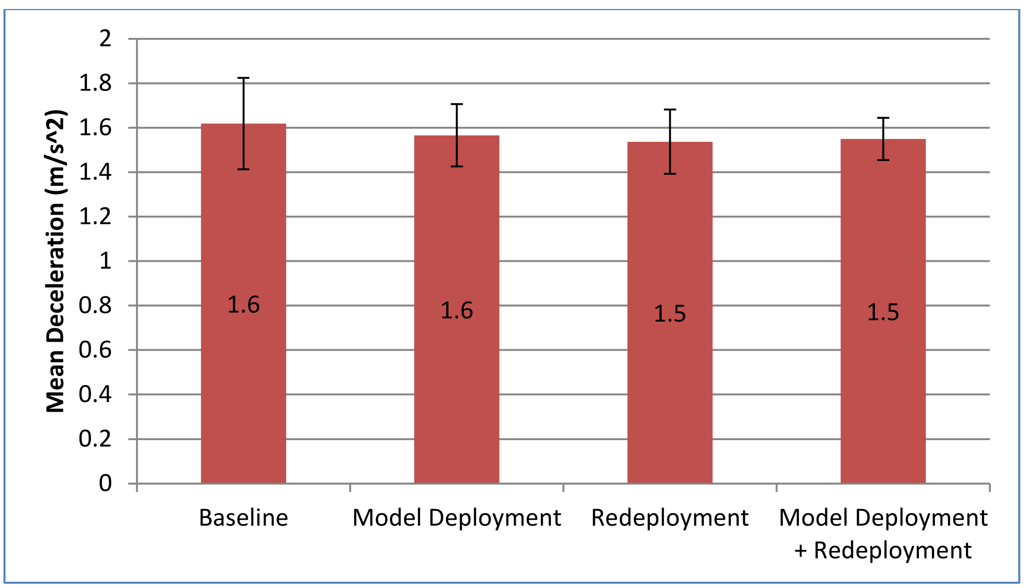

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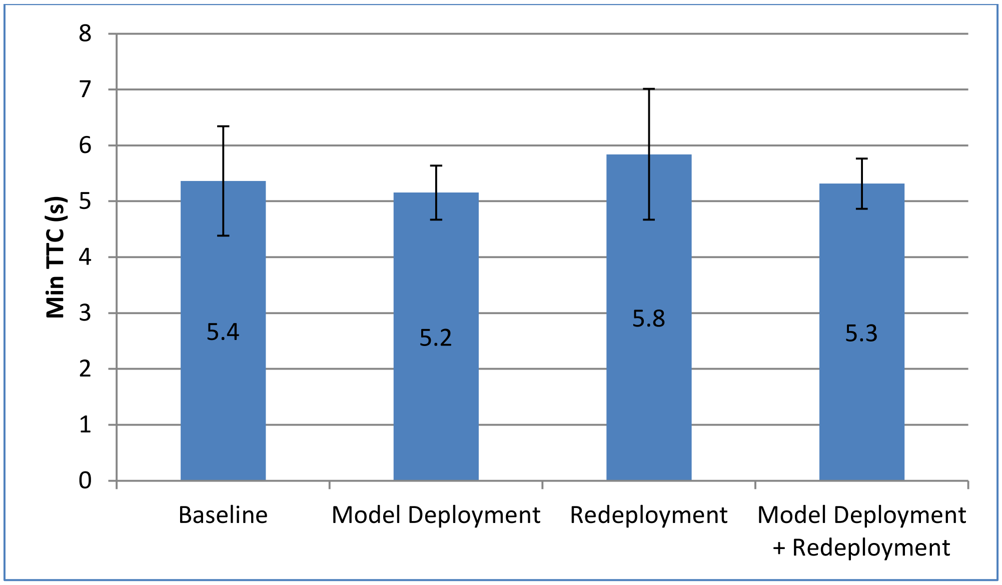
Figure 3-11. Mean Mean Deceleration for LVS/LVM FCW Alerts, by Test Period

3.2.1.1.6 Minimum TTC

Minimum TTC is the shortest TTC observed during an FCW braking event and represents the maximum level of severity of the event. The mean values of minimum TTC for each test period are shown for remote vehicle decelerating scenarios in Figure 3-12 and for remote vehicle stopped/constant speed scenarios in Figure 3-13

The IE did not observe any changes in the minimum TTC between test periods meaning that drivers did not brake earlier when they received FCW alerts.



Volpe

Figure 3-12. Mean Minimum TTC for LVD FCW Alerts, by Test Period

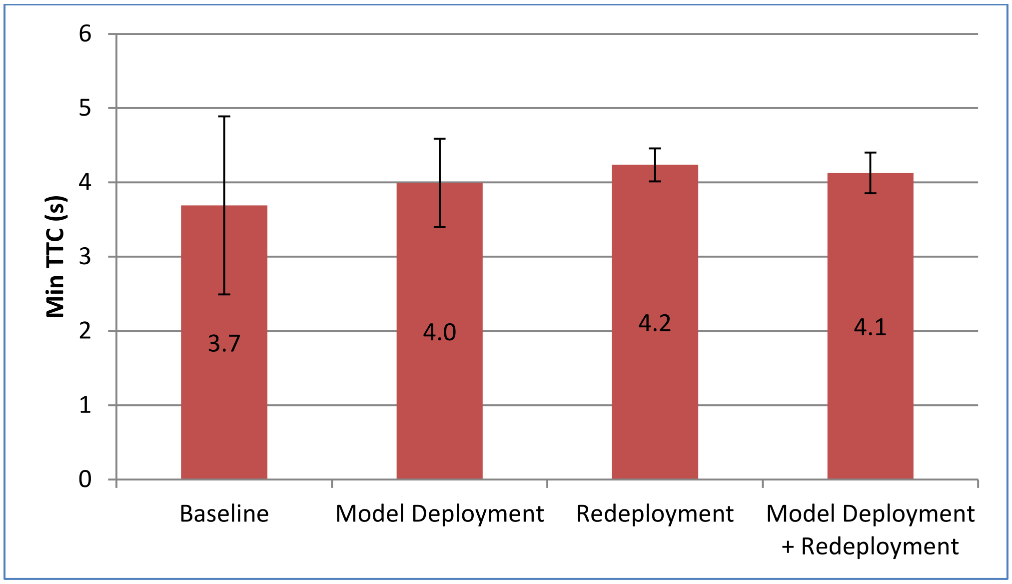


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Figure 3-13. Mean Minimum TTC for LVS/LVM FCW Alerts, by Test Period

3.2.1.2 CSW

The analysis of response to CSW alerts includes CSW events issued on the Bonisteel Boulevard equipped curve where the alert was issued when the TRP bus was either approaching or already in the equipped curve (true events).[18] As described in Section 2.2.2, 295 of the 519 CSW alerts analyzed were true alerts with 293 of these true alerts issued on the Bonisteel Boulevard equipped curve. Figure 3-14 shows the breakdown of the 293 true CSW alerts by test period.

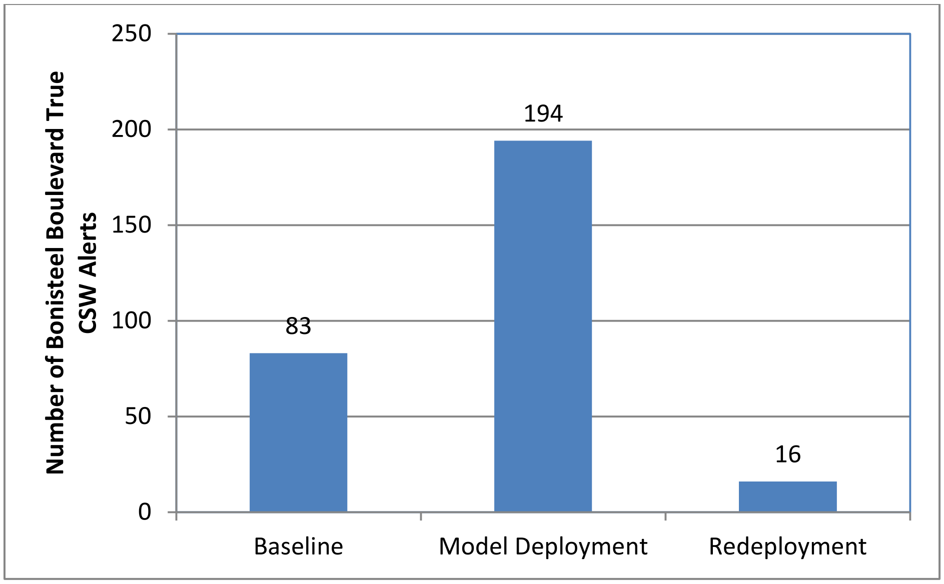

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Figure 3-14. Breakdown of True CSW Alerts by Test Period

Drivers braked in response to only 26 of the 293 true CSW alerts (9 percent). Because there is no imminent threat in a CSW alert scenario (for example, a remote vehicle that the bus will hit) it is possible that drivers responded to alerts more subtly by only releasing the throttle. Since the IE did not have throttle data to measure throttle response to CSW alerts all true CSW events were included in the driver behavior analysis[19].

3.2.1.2.1 Initial Conditions

Figure 3-15 shows the speed of the TRP vehicle at the time of the CSW alerts. Based on the 95 percent confidence interval, the speed at the alert onset during the Baseline period (14.3 m/s) was slightly lower than the speed at the alert onset during the Model Deployment period (15.7 m/s). This difference is likely caused by the change in threshold speed for the CSW alert during the Baseline period. For most of the Baseline test period, the CSW application was set to trigger a warning at 5 mph over the speed limit (30 mph,13.4 m/s), compared to 10 mph over the speed limit (35 mph, 15.6 m/s) during the rest of the field test. It is likely these

[18] Two true events were issued on the Plymouth Road equipped curve. Both of these events were issued during the Baseline period. For consistency (the speed threshold set to trigger a CSW alert was higher for Plymouth Road than Bonisteel Boulevard), these two events were excluded from the driver response analysis.

[19] With the exception of the analysis of brake response time, which only included alerts that had a braking response within 5 seconds of the alert.

alerts issued at lower speeds are the reason for the small change in alert speed between the Baseline and Model Deployment.

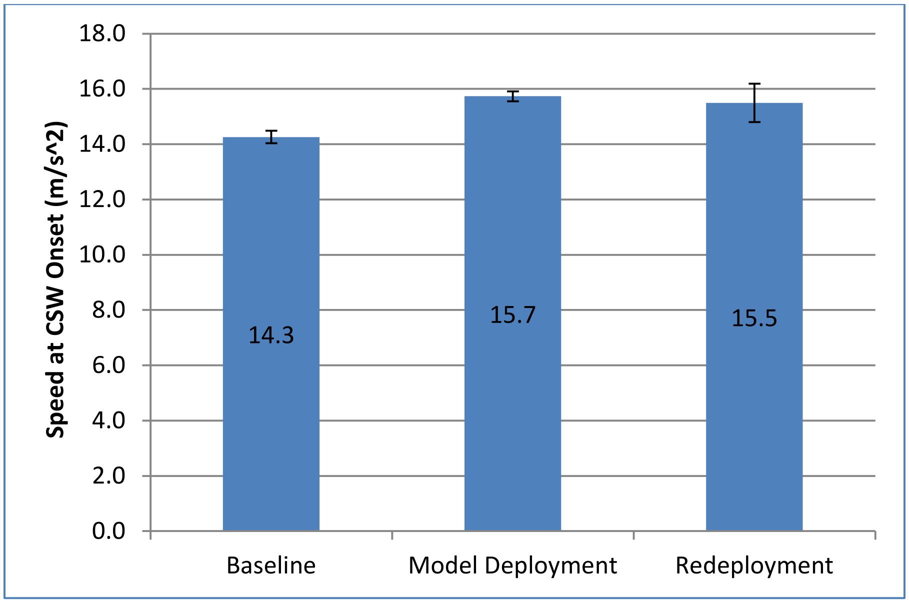

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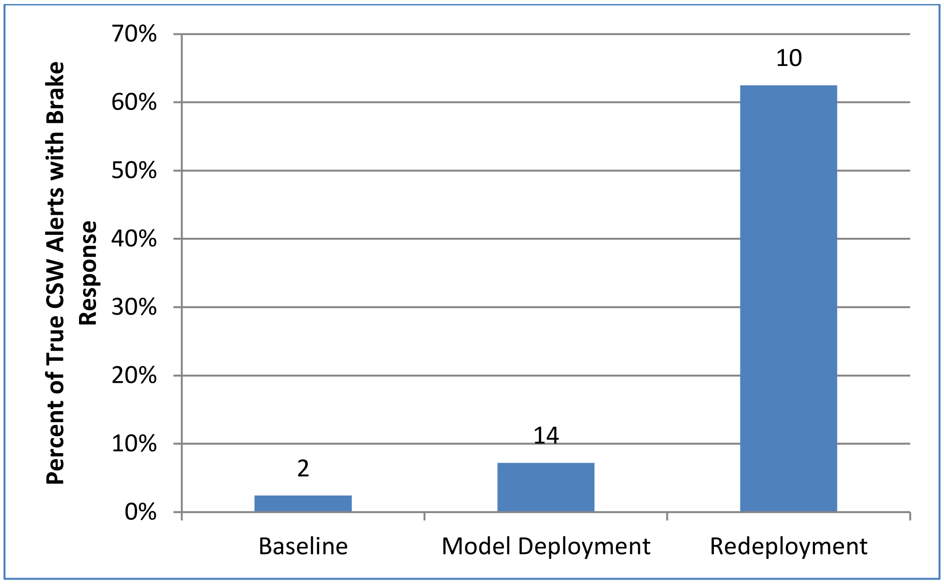
Figure 3-15. Mean TRP Speed at CSW Alert Time

3.2.1.2.2 Frequency of Response

Interestingly, the frequency of braking response varies by test period. Figure 3-16 shows the percentage of alerts in each test period where the driver responded by braking within 5 seconds of the alert. While the sample size of alerts from the Redeployment test period is much smaller than the other test periods, the limited data shows a much higher rate of braking response to CSW alerts. The speed at alert time did not vary significantly between Model Deployment and Redeployment, which suggests that the change in brake response rate was due to the changes made to the driver interface prior to Redeployment. During Redeployment the display was placed closer to the driver, the visual display stayed on longer, and the auditory tones were replaced by verbal messages. These changes may have made drivers more likely to brake in response to the alert rather than only releasing or reducing the throttle, or not responding at all.

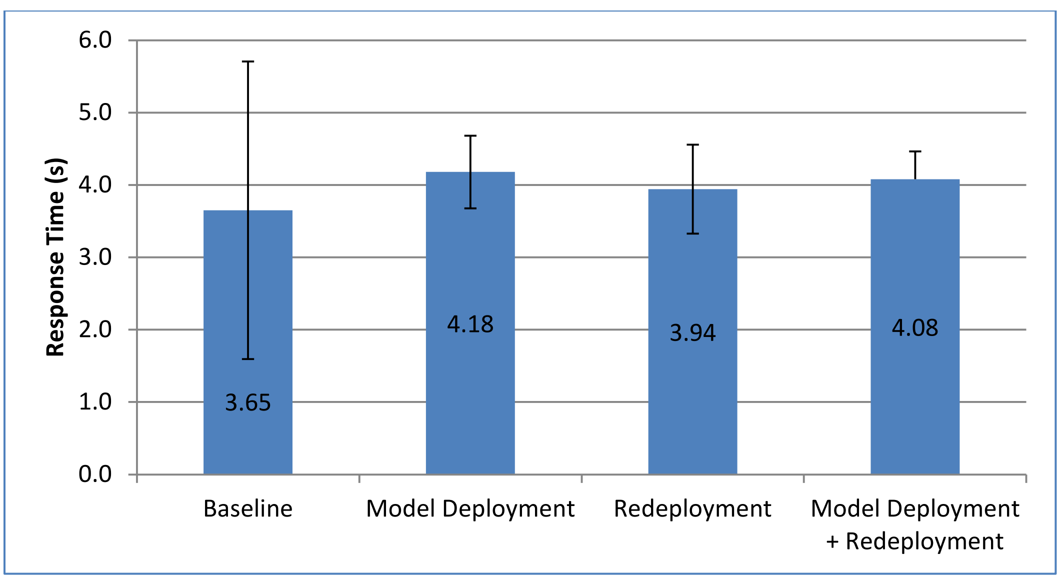


Volpe

Figure 3-16. Percentage of Bonisteel Boulevard True CSW Alerts with Brake Response

3.2.1.2.3 Brake Response Time

In addition to response frequency, the IE also analyzed response time for the 26 CSW events where the driver braked within 5 seconds of the alert onset. Figure 3-17 shows the mean response time by test period. There were no observed differences in brake response time between test periods meaning that drivers did not brake earlier when CSW alerts were issued.



Volpe

Figure 3-17. Mean Response Time to CSW Alerts by Test Period

3.2.1.2.4 Longitudinal Deceleration

Peak deceleration for the bus represents the maximum instantaneous rate of deceleration within 5 seconds of the CSW alert. It represents how aggressively the driver is slowing down in response to the alert. Mean deceleration is a measure of the average deceleration within 5 seconds of the alert onset. It represents the overall magnitude of the driver response to the alert. Figure 3-18 shows the results for peak deceleration by test period while Figure 3-19 shows the results for mean deceleration by test period. There were statistically significant increases between the Baseline and Model Deployment test periods, and between the Model Deployment and the Redeployment test periods for both deceleration metrics. This shows that drivers slowed down more and slowed down more aggressively when they received CSW warnings compared to when no warnings were issued. It also shows drivers slowed down more and slowed down more aggressively using the driver interface implemented during Redeployment compared to the original driver interface. The latter result is likely due to the increase in response frequency, since a braking response produces a higher peak and mean deceleration compared to only releasing or reducing the throttle.

When the Model Deployment and Redeployment test periods were combined there were also statistically significant increases in both peak and mean deceleration compared to the Baseline period.

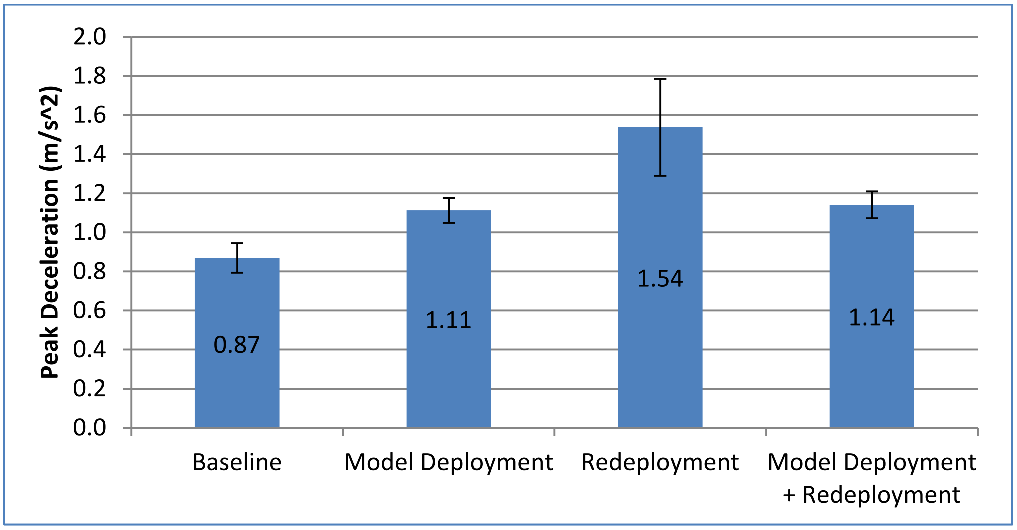


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Figure 3-18. Mean Peak Longitudinal Deceleration in Response to CSW Alerts, by Test Period

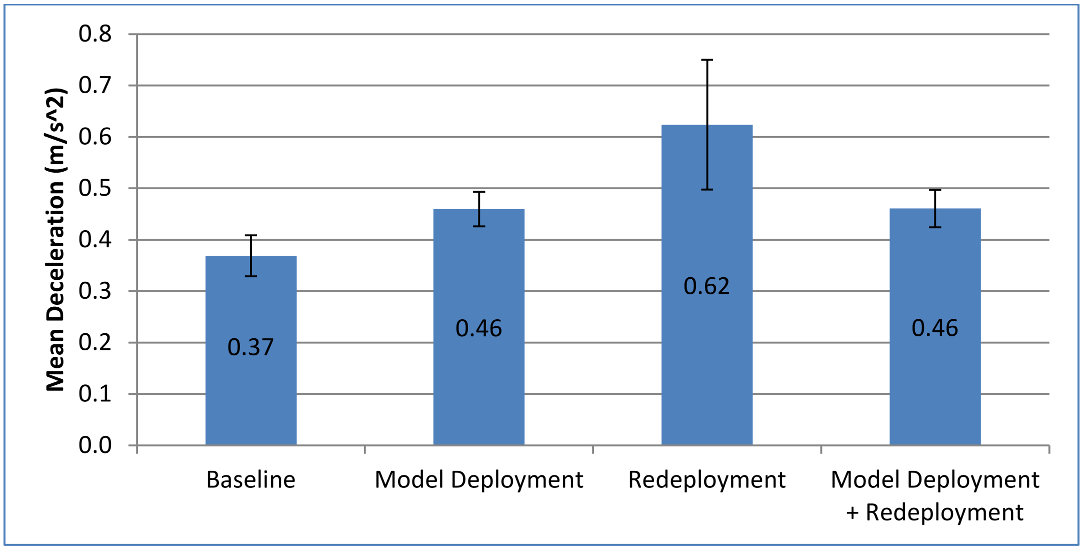

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Figure 3-19. Mean Mean Longitudinal Deceleration in Response to CSW Alerts, by Test Period

3.2.1.2.5 Lateral Acceleration

Lateral acceleration is a measure that shows how aggressively a driver is navigating a curve. Traveling slowly around a curve produces a lower lateral acceleration than traveling more quickly around the same curve. This means higher measures of lateral acceleration are associated with faster and more aggressive driving. Figure 3-20 and Figure 3-21 show the results for mean and peak lateral acceleration, respectively. Similar to the metrics for longitudinal deceleration in the previous subsection there were statistical differences for both of these lateral acceleration metrics between the Baseline and Model Deployment test periods and between the Model Deployment and Redeployment test periods. Mean lateral acceleration showed a statistical reduction from the Baseline period to the Redeployment test period, whereas peak lateral acceleration did not.

Differences between Baseline and Model Deployment/Redeployment lateral acceleration metrics could be because the alerts were issued at a lower speed during the Baseline period, but differences between the Model Deployment and Redeployment test periods are likely due to changes made to the driver interface.

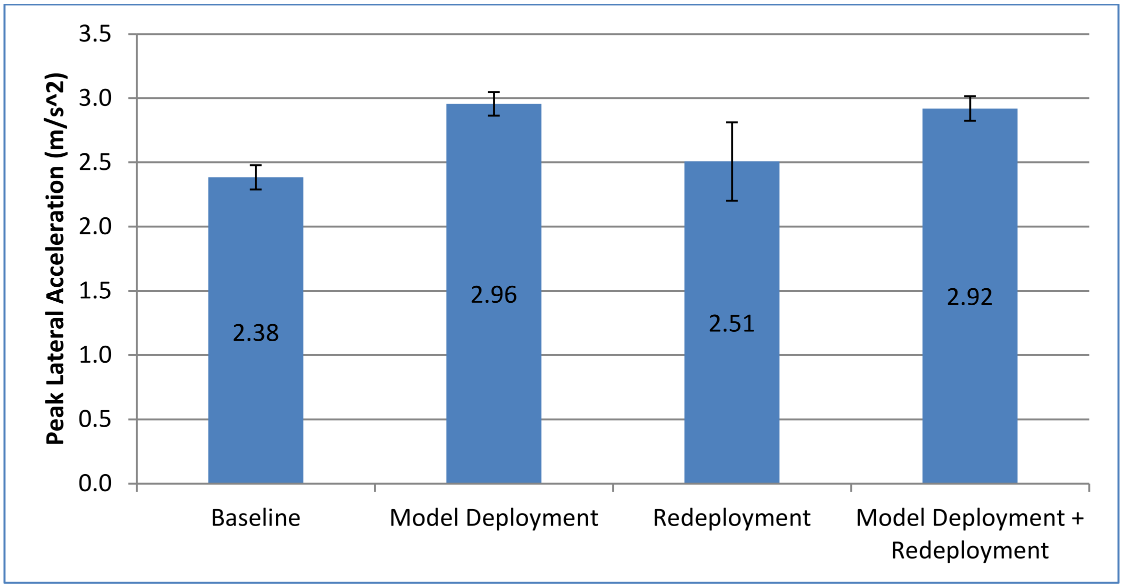

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Figure 3-20. Mean Peak Lateral Acceleration in Response to CSW Alerts, by Test Period

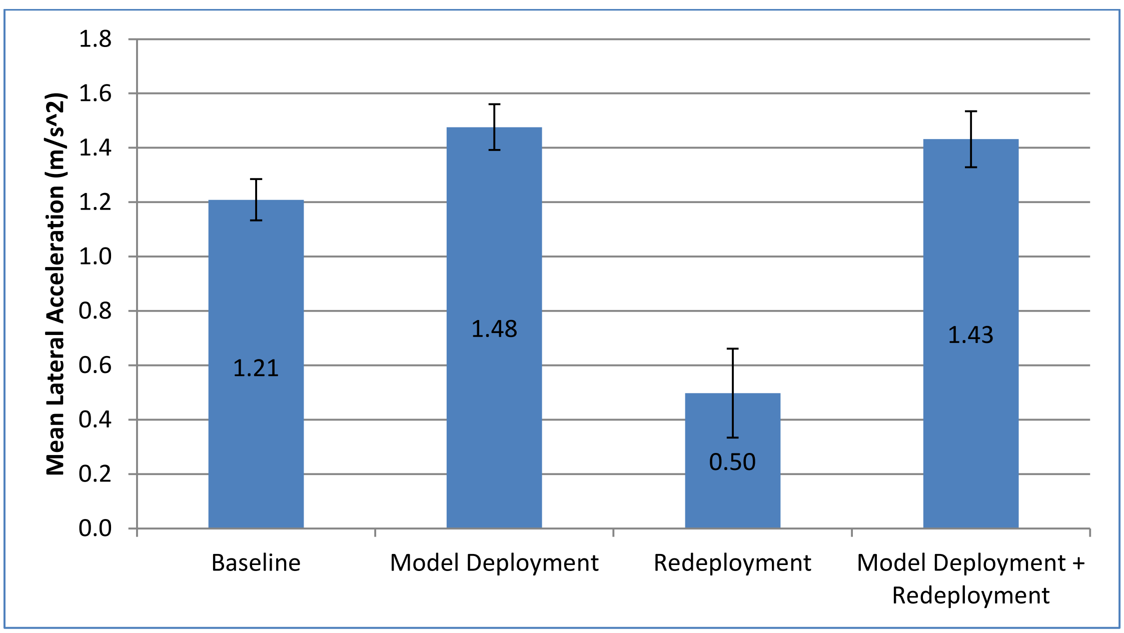

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Figure 3-21. Mean Mean Lateral Acceleration in Response to CSW Alerts, by Test Period

3.2.1.3 EEBL

The EEBL application warns the TRP driver when a vehicle ahead (either in the same lane or in an adjacent lane) is decelerating quickly. This event serves as a cautionary warning that an event may transpire that will require the TRP driver to brake. Figure 3-22 shows the breakdown of the 27 EEBL alerts issued during the Model Deployment field test, by test period. Drivers braked in response to only 3 of the 27 EEBL alerts (11 percent), all of which occurred during the Model Deployment test period. Similar to the CSW safety application, there is not always an imminent threat when an EEBL alert is issued, so it is possible that drivers would respond by only releasing or decreasing the throttle (deceleration was observed after each of the 27 events). This being the case, the IE included all EEBL alerts in the safety impact analysis.

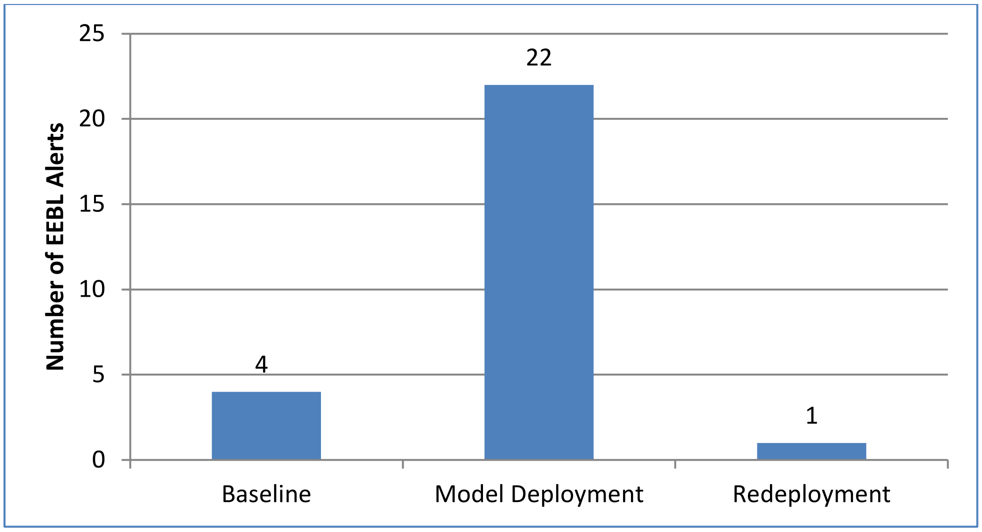

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Figure 3-22. Breakdown of EEBL Alerts, by Test Period

Since only one EEBL alert was issued during the Redeployment test period, the IE did not analyze Redeployment data separately for EEBL and combined the Redeployment and Model Deployment test periods.

3.2.1.3.1 Peak Deceleration

Figure 3-23 shows the peak deceleration, within 5 seconds of EEBL alerts, for the Baseline and Model Deployment/Redeployment test periods. Peak deceleration ranged from 1.4 to 1.8 m/s^2 during the Baseline and from 0.4 to 2.1 m/s^2 during the Model Deployment and Redeployment. The IE did not observe any differences in peak deceleration between test periods meaning that drivers did not decelerate differently when they received EEBL warnings.

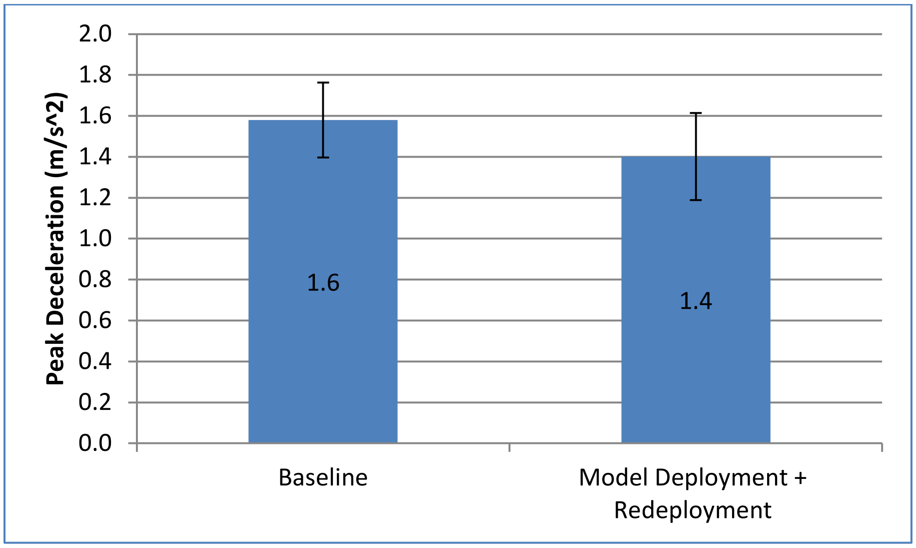

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Figure 3-23. Mean Peak Deceleration for EEBL Alerts, by Test Period

3.2.1.3.2 Mean Deceleration

Figure 3-24 shows the mean deceleration, within 5 seconds of EEBL alerts for the Baseline and Model Deployment and Redeployment test periods. Mean deceleration ranged from 0.7 to 1.0 m/s^2 during the Baseline and from 0.2 to 1.4 m/s^2 during the Model Deployment and Redeployment test periods. The IE did not observe any differences in mean deceleration between test periods meaning that drivers did not decelerate differently when they received EEBL warnings.

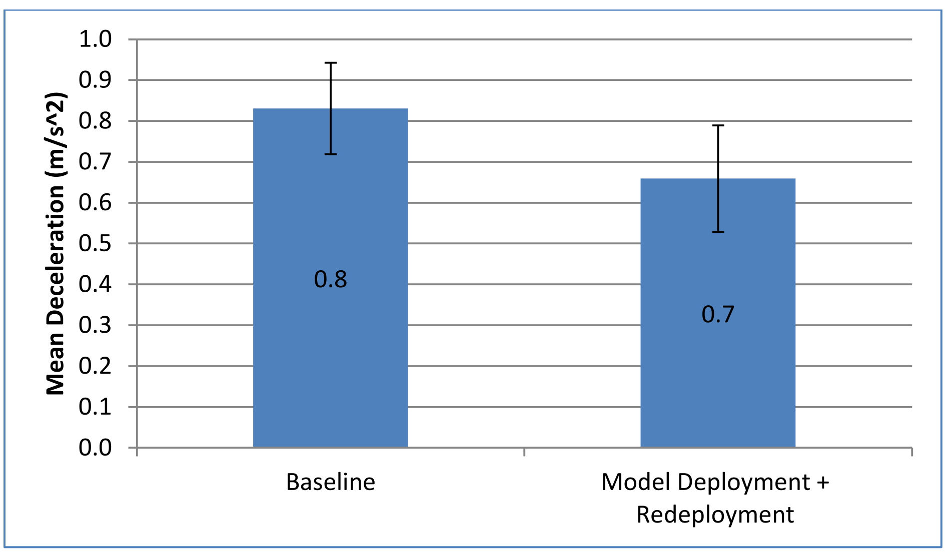

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Figure 3-24. Mean Mean Deceleration for EEBL Alerts, by Test Period

3.2.1.4 PCW

The analysis of driver response to PCW alerts includes only true PCW warnings (the bus traversed the equipped crosswalk and a pedestrian was present in the crosswalk). Of the 505 PCW warnings analyzed from the Model Deployment and Redeployment test periods, 37 (7 percent) were true alerts. Figure 3-25 shows the breakdown of true PCW alerts by test period.

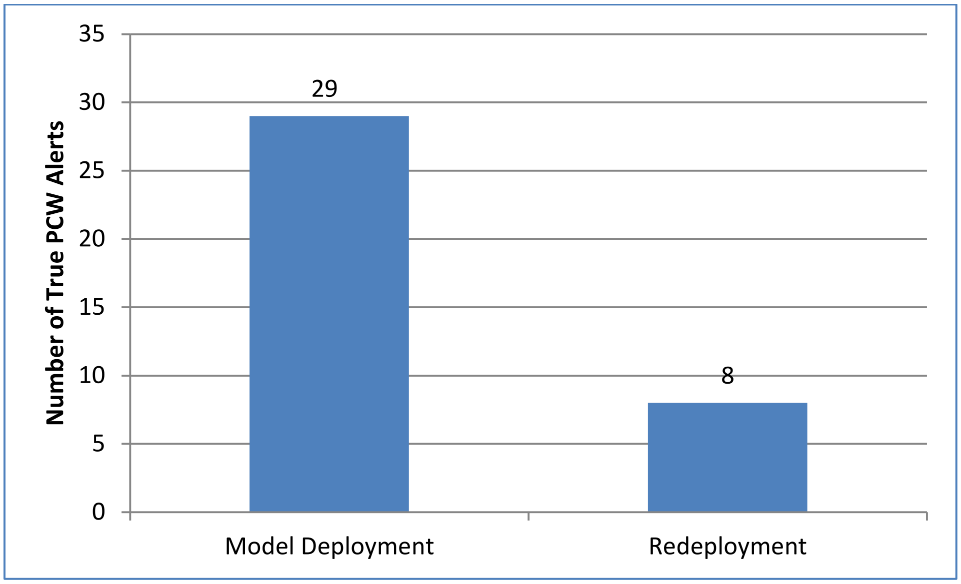

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Figure 3-25. Number of True PCW Alerts Used in Driver Response Analysis, by Test Period

3.2.1.4.1 Rate of Response

The IE analyzed response to PCW alerts based on response rate. A driver was considered to have braked in response to a PCW alert if they were proceeding into the crosswalk but then braked after receiving the alert to allow the pedestrian to cross. Drivers braked in response to four of the 37 true PCW alerts (11 percent). Two of the events with a driver response were from the Model Deployment test period, and two were from the Redeployment test period. In each of these four scenarios based on the video analysis it appeared that the alert made the driver aware that there was a pedestrian in the crosswalk.

While rate of response to true PCW alerts is relatively low overall, it is important to note that the PCW application is designed to alert drivers of the presence of pedestrians, independent of the bus movement. This means that the driver will receive an alert regardless of whether they are sitting at a red light or actively proceeding into the crosswalk. Of the 37 true PCW alerts, 11 (30 percent) were issued when the TRP bus stopped at the intersection. No driver response would be expected in these scenarios.

For the remaining 22 events, the driver was either already braking at the time of the alert (5 events), braked after the alert in response to either a red traffic signal or in preparation for turning at the intersection (2 events), or the driver did not need to respond because the pedestrian had already cleared/was clearing the path of the bus at the time of the alert (15 events).

3.2.1.5 VTRW

As described in 2.2.5, 11 VTRW alerts where the RV followed the prescribed path (true alerts) were issued during the Model Deployment test period (7 cautionary and 4 imminent). The RV did not follow the prescribed path in any of the VTRWs during the Redeployment test period. The IE included these 11 True RVTWs in the analysis of driver response to VTRWs.

In 9 of the 11 true events, the bus was stopped and the driver did not intend to proceed, (see Sections 2.2.5.2.1 and 2.2.5.3.1) so the driver did not respond to the alert. In the other two events (both cautionary) the TRP driver did intend to proceed. In one of these events the remote vehicle stopped to let the TRP driver proceed, and in the other event the TRP driver was stopped at the time of the alert and waiting for the remote vehicle to pass before proceeding. In neither of these cases did the driver appear to alter their behavior in response to the alert.

3.2.2 Driver Attention

In the 1,713 alert events analyzed, there were no events where the TRP driver had their eyes off the driving task.[20] This suggests that driver distraction did not cause any of the alert events.

Even though the IE observed instances of drivers engaging in secondary tasks (without turning their gaze away from the driving task), these were very rare and only accounted for less than 4 percent of all analyzed alert events.

Figure 3-26 shows the breakdown of secondary task percentage by safety application. The labels on the top of the bars represent the total number of alerts for each application where secondary tasks were observed. There were secondary tasks in 1 percent of the FCW alert scenarios and in less than 1 percent of the EEBL and CSW alert scenarios. The PCW and VTRW safety applications had a higher percentage of alerts with secondary tasks (8 and 25 percent respectively). This is probably because PCW and VTRW alerts, by design, issue alerts in situations when the bus is stopped (e.g. when at a red light or when stopped at a bus stop), and drivers are more likely to engage in secondary tasks when stopped than when the bus is moving. In 31 of the 39 PCW events where the driver engaged in secondary tasks, the bus was stopped at the intersection within 10 seconds prior to the warning being issued (the time period in which secondary tasks were coded). Since VTRW alerts are designed to be issued only when the TRP bus is stopped at a VTRW enabled bus stop, all 17 of the VTRW alerts with secondary tasks were issued when the bus was stopped. In16 of these 17 events the bus driver did not show intent to proceed from the bus stop at the time of the alert.

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[20] "Eyes off driving task" is defined as an event where the driver looks away from the driving task for 1.5 continuous seconds within 5 seconds of the alert onset.

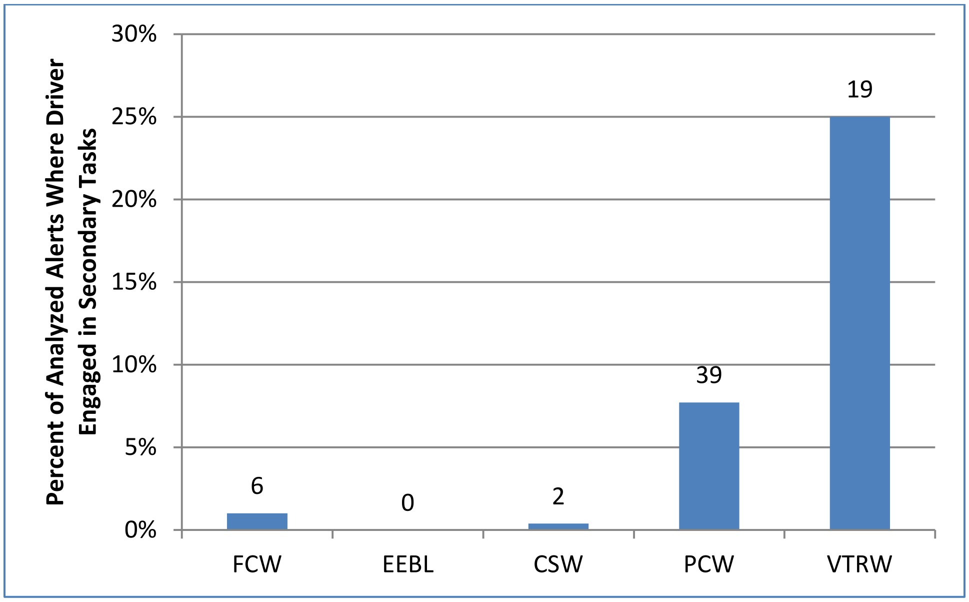

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Figure 3-26. Percent of Analyzed Alerts with Secondary Task Engagement, by Safety Application

Table 3-2 shows the breakdown of the frequency of individual secondary tasks by safety application.

Table 3-2. Frequency of Secondary Tasks by Safety Application

Secondary Task	FCW	EEBL	CSW	PCW	VTRW
Reaching for object	2		2	6	3
Eating/drinking	3			16	1
Adjusting controls	1			1	
Looking at clipboard/papers				3	8
Talking to/looking at passengers				2	
Using dispatch radio				4	
Grooming				3	
Using cell phone				2	5
Searching interior				1	2
Yawning				1	

Volpe

Overall, TRP drivers in the Model Deployment field test rarely engaged in secondary tasks, and generally did so only when the bus was stopped. It is unlikely that driving with the safety applications had a negative impact on their attention to the driving task. The IE did not observe any examples of unintended consequences from driving with the safety applications during the Model Deployment field test.

4 Driver Acceptance

The IE looked at driver acceptance of the V2V and V2I safety applications for transit buses in the Safety Pilot Model Deployment using two sets of data: a post-participation survey (see Appendix D) developed by UMTRI, Battelle, and the IE, and feedback from focus groups conducted by UMTRI (see Appendix E). After briefly showing the DVI for the TRP, this section describes the methodology used to analyze the survey and focus group data, presents the results of these analyses,

4.1 Introduction

This subsection defines the term “driver acceptance” and describes the objectives of the analysis and the factors that may complicate interpretation of the results.

4.1.1 What is Driver Acceptance?

Driver acceptance is difficult to define precisely because it is a complicated concept 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*: are the TRP safety applications easy to use and understand?
- *Perceived Safety Benefits*: will TRP technology contribute to your driving safety?
- *Unintended Consequences:* are you concerned about distraction or overreliance?
- *Desirability:* do you want to have and use TRP safety applications in your vehicle?
- *Privacy:* how do you feel about privacy issues raised by TRP technologies?

4.1.2 Analysis Objectives

The objectives of this analysis are to assess driver acceptance of the TRP based on the five factors listed in Section 4.1.1.

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. Since these relationships between experience and acceptance are lost when participants are averaged together, the IE explored the relationship driver by driver. For example, survey responses were correlated with certain aspects of individual driver experience, especially the frequency of true or false alerts the drivers felt they received.

4.2 Driver-Vehicle Interface

The DVI for the TRP consisted primarily of a screen mounted above the dashboard and slightly to the right of the driver (Figure 4-1).

Battelle

Figure 4-1. The TRP Display Screen

As discussed in Section 1.1.1 each application had both cautionary (yellow) and crash-imminent (red) warnings. FCW alerts showed a vehicle ahead (Figure 4-2); PCW showed a pedestrian on the crosswalk (Figure 4-3); VTRW showed an overhead view of a vehicle turning right in front of the bus (Battelle

Figure 4-4); EEBL showed the location of a vehicle braking ahead in terms of its lane position (Figure 4-5); and CSW showed a picture of a bus entering a turn (Figure 4-6). The auditory tones for all types of alerts (PCW, VTRW, CSW, EEBL, FCW) and levels of alert for each type (caution and warning) were all the same in the Model Deployment—they all sounded the same and relied upon the driver looking at the display to identify the specific type and level of alert. In the Redeployment the cautions and warnings were given different verbal messages.

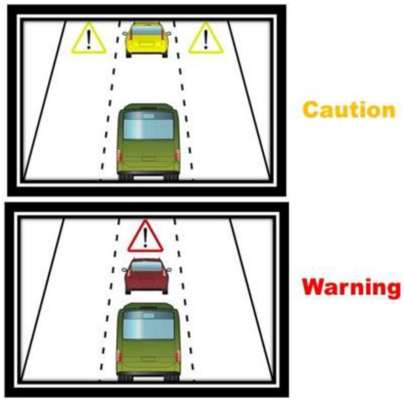

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Figure 4-2. FCW Alerts

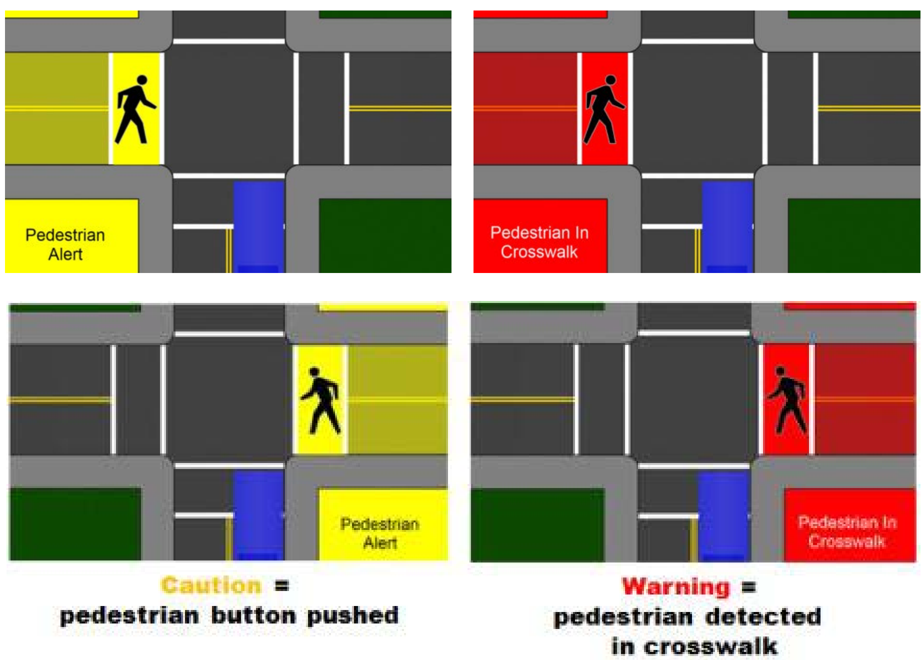

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Figure 4-3. PCW Alerts

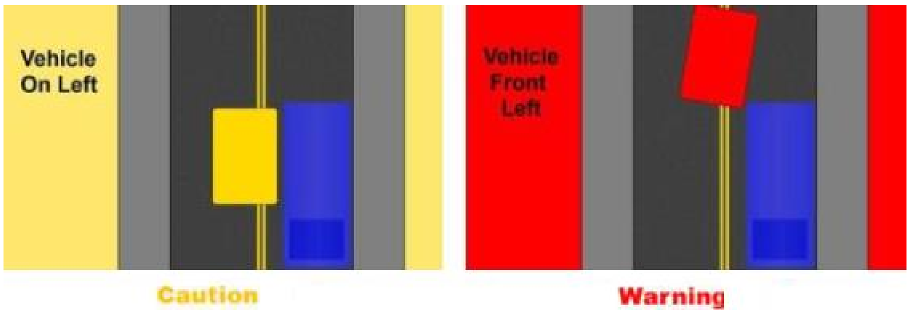

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Figure 4-4. VTRW Alerts

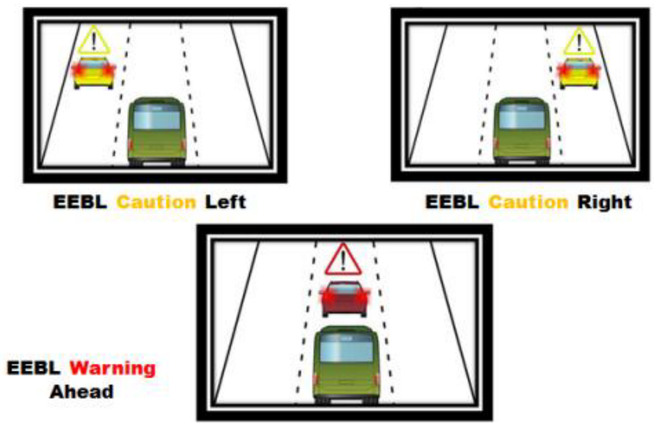

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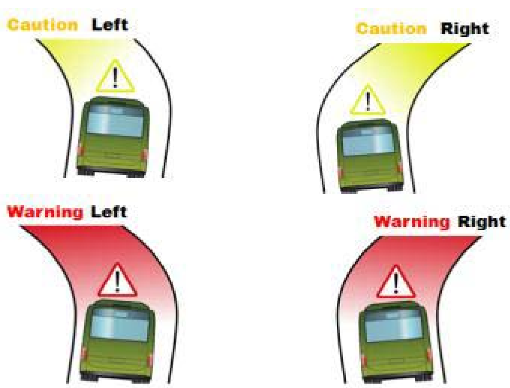
Figure 4-5. EEBL Alerts



Battelle

Figure 4-6. CSW Alerts

4.3 Methodology

This subsection describes the methodology used to analyze the surveys completed by participants at the end of the study. Thirty-two of the 40 participants who drove during the Model Deployment test period completed the survey, and 27 of the 35 participants who drove during the Redeployment test period completed the survey. The methodology was the same for both the Model Deployment and the Redeployment.

4.3.1 "Top-7" and "Low-25"

During the Model Deployment test period, the amount of time spent driving with the system varied considerably between participants. Some participants drove nearly 20 percent of the total TRP driving hours, others less than 1 percent, and many did not drive the TRP-equipped buses at all. Out of the 32 participants who filled out surveys, 7 participants (the "Top-7") drove 86 percent of the total driving hours (Table 4-1). Twenty-five participants (the"Low-25") drove the remaining driving hours; each driving less than 1 percent of the total hours driven.

Since the purpose of this analysis was to estimate driver acceptance based on actual experience using the technology, the IE separated responses by participants with experience into two categories. The analysis focused primarily on the Top-7 participants, with responses by the Low-25 reported separately.

Table 4-1. Percentage of Total Hours Driven by the Top-7 Participants

Participant Number	Percent of Total Driving Hours
2	22.4%
3	19.0%
5	16.7%
1	14.3%
4	10.2%
6	1.9%
23	1.3%

Volpe

An alternative approach would have been to divide drivers based on the number of alerts they received, rather than by the number of hours they drove. This was not feasible because individual drivers were not identified in the objective driving data.

Table 4-2 shows the age distribution of the Top-7 and Low-25 participants. The Low-25 group contained a greater proportion of younger drivers than was the Top-7 group.

Table 4-2. Age Groups of Participants in the Top-7 and Low-25 groups

	20s	30s	40s	50s	60s	Total
Top-7	2	0	1	4	0	7
Low-25	14	2	4	2	3	25

Volpe

4.3.2 Likert-Scale Responses

One of the downsides to survey questions using a scale of 1 to 7 is their built-in subjectivity. One participant's rating of 5 might be equivalent to another's 7. To remove some of this subjectivity, the IE 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). The IE took a conservative approach with neutral scores by counting scores of 3 and 5 as "neutral."

In general, the Likert-scale responses were displayed graphically as either bar graphs or tables. Bar graphs show the total results for groups of drivers, e.g., Top-7 or Low-25 participants. In bar graphs the number of participants who answered in a given category is listed within the bar. Tables show results by question and by individual driver. Tables were generally used when it was useful to compare the responses by one participant to multiple questions as well as to compare between participants for the same question. Unless otherwise noted, participants were listed in descending order by the number of hours driving with the TRP system.

Due to the small number of TRP drivers in the Model Deployment field test, the quantitative analyses focused on descriptive statistics and in-depth analyses of individual drivers rather than inferential statistics. In the few cases where inferential statistics were used, such as comparing Model Deployment and Redeployment survey questions, nonparametric tests were used since they are more appropriate for non-interval data such as Likert-scale responses. For the same reason, where appropriate the median and interquartile range (IQR)[21] is reported rather than the mean.

4.3.3 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 summarized in tables and are included in this section of the report to illustrate and further explain the Likert-scale responses.

4.3.4 Model Deployment Versus Redeployment

After completing the Redeployment, participants filled out a similar survey to the Model Deployment survey, with additional questions about improvements made to the TRP applications. Since the purpose of collecting subjective data was to understand the impact of changes made to the TRP system, the IE analysis of the Redeployment data focused on comparing responses to similar questions between the Model Deployment and the Redeployment test periods, ideally using within-subject comparisons, i.e., comparing each participant's responses in the Model Deployment to the same participant's responses in the Redeployment.

[21] The IQR indicates the spread of the data and is calculated as the difference between the first and the third quartiles.

4.4 Survey Results

This subsection presents survey results for the Model Deployment and the Redeployment test periods. Surveys were filled out by participants after their involvement in the Model Deployment was complete. For those who took part in the Redeployment, they filled out an additional survey after completing their participation in the Redeployment.

4.4.1 Model Deployment

Results are broken down into the following subcategories:

- *Overall Impressions*: overall impressions of the combined suite of safety applications
- *Individual Safety Applications versus the Combined Safety Package:* comparison of acceptance between the different applications and the system overall
- Separate sections for each application focusing on which factors influenced acceptance:
  - FCW
  - PCW
  - VTRW
  - EEBL
  - CSW
- *Privacy*: concerns about privacy issues related to connected-vehicle technology
- *Unintended Consequences*: including driver distraction or overreliance caused by the applications

4.4.1.1 Overall Impressions

This subsection describes overall impressions of the combined suite of safety applications.

4.4.1.1.1 Were any Near Misses Avoided Because of the System?

The bottom line in a warning system such as this is whether or not the system helped to prevent any crashes. Given the rarity of crashes and near misses in real life, it is extremely unlikely that any would be observed in a study such as the Safety Pilot. Nonetheless, one of the Top-7 participants answered positively to the question "Were any near misses avoided because of the presence of TRP? If so, please describe" by commenting that “a car with the same system [pulled] in front of me.” Even though no Low-25 participants reported any such event, one commented that “the things pointed out were things that I have to pay close attention to all the time due to the nature of the job.”

4.4.1.1.2 What Did Participants Like the Most/Least and Were There any Difficulties?

Table 4-3 lists all responses by the Top-7 participants to the questions “What did you like most/least about the Transit Safety Retrofit Package?,” “Please describe any difficulties you encountered with the Transit Safety Retrofit Package,” and “Were the issues resolved?” The only feature listed as most liked by more than one participant was the PCW, which two participants liked. Three participants listed false alerts as least liked. The cameras mounted in the bus for research purposes (but would not be part of a production system) were listed once both as least and most liked (by different participants).

Table 4-3. TRP Features Liked Most, Liked Least, and Difficulties Encountered by Top-7 Participants

Driver ID	Liked Most	Liked Least	Difficulties Encountered	Difficulties Resolved?
2	"The cross walk notices"	"False alarms"	"None"	N/A
3	-	"False readings"	"A lot of the time the system was down"	No
5	"Some features were helpful at times"	"The camera"	"Sometimes distracted by beeping at wrong times"	No
1	"I liked how it gave me a reassuring feeling that I was not doing anything wrong since it did not warn me about anything."	"Nothing"	"No difficulties"	N/A
4	"No interaction or responses [was] required"	"The accuracy of what lane of travel I was in. I would receive alerts and warnings that weren't in my lane."	"The brightness of the screen was an issue at night"	Yes
6	"I like the idea that there are cameras everywhere to record everything."	"There was hardly any response from it. I rarely interacted with another vehicle equipped with this system."	"The tablet wouldn't charge and it would go into an endless restart cycle of dying and getting enough juice to power on and die again."	N/A
23	"The crosswalk alert"	"None"	"None"	N/A

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Three Low-25 participants named the PCW as most liked—no other applications were called out specifically. For least liked, 5 Low-25 participants named distraction caused by the system and 4 named false alerts.

4.4.1.1.3 Overall Satisfaction

Overall satisfaction with the TRP was mostly neutral (Figure 4-7), with 4 out of 7 (57 percent) Top-7 participants and 69 percent of Low-25 participants giving neutral replies in response to the statement "Overall, I was satisfied with the Transit Safety Retrofit Package." There were slightly more positive replies than negative, with two positive and one negative Top-7 ratings and 25 percent compared to 6 percent for Low-25 ratings. The only comment made by a Top-7 participant was by Driver 5, who rated disagreement with the statement and said it "didn't work."

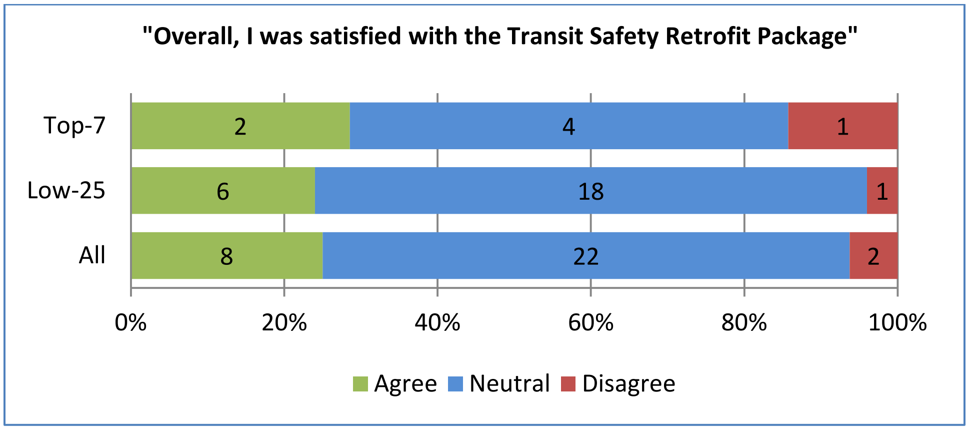

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Figure 4-7. Overall Satisfaction with the TRP

4.4.1.1.4 Impact on Job Performance

In addition to driving safely, transit operators have to perform their job while using the TRP technology. When asked "How does the Transit Safety Retrofit Package impact the ability to do your job (positively and/or negatively)?" participants had mixed opinions (Table 4-4). The Low-25 participants—who had less experience with the warning system—were slightly more optimistic, with 8 positive responses, 10 neutral, and only 1 negative.

Table 4-4. Estimated Impact on Job Performance

	Driver ID	Job Performance Impact
Top-7	**2**	"Negatively—makes you turn your head in wrong direction"
	3	"The system does allow for me to adjust some of my driving patterns sooner than I would have adjusted them myself"
	5	"Had no impact"
	1	"It is not a necessity because I am a safe driver and never take dangerous [illegible]"
	4	"Does not affect it at all. I can choose to ignore the warnings and did because most of the time they weren't warranted"
	6	"I generally forgot it was doing anything until I'd approach another vehicle with the system. In those instances I usually found it a little overwhelming because I was never close to rear ending a vehicle but the system made it feel that way"
	23	"It helps when someone is crossing the street"
Low-25	**-**	"It does make you more aware of pedestrians which is probably the most helpful in the dark but the other warnings do require you to take your eyes off the road for several seconds"

Driver ID	Job Performance Impact
-	"Sometimes a warning to brake is good because I don't notice how fast a line of cars is coming up and then my braking isn't smooth"
-	"It makes drivers stupid/worse because they don't have to rely on their skills/training"

Volpe

4.4.1.1.5 Perceived Increase in Driving Safety

Participants rated the perceived safety benefits of the system by rating their agreement with the statement "Overall, I think the Transit Safety Retrofit Package increased by driving safety." Figure 4-8 shows responses were more negative among Top-7 participants where 4 out of 7 (57 percent) thought there was no increase in driving safety and only one participant (14 percent) thought there was an increase. Among Low-25 participants, the responses were slightly more evenly distributed, with 47 percent neutral, but with 38 percent still disagreed that there was an increase. There were no comments from Top-7 participants. The only relevant comment by a Low-25 participant was "I'm a safe driver, it had no impact."

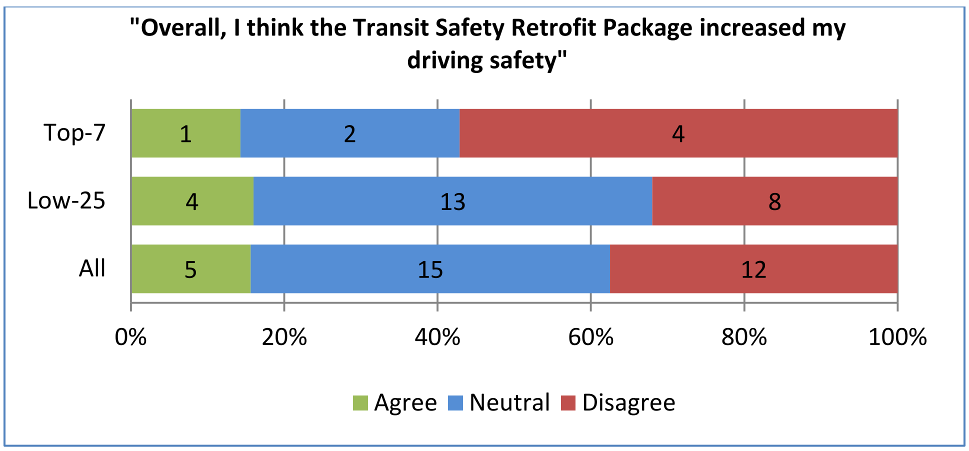

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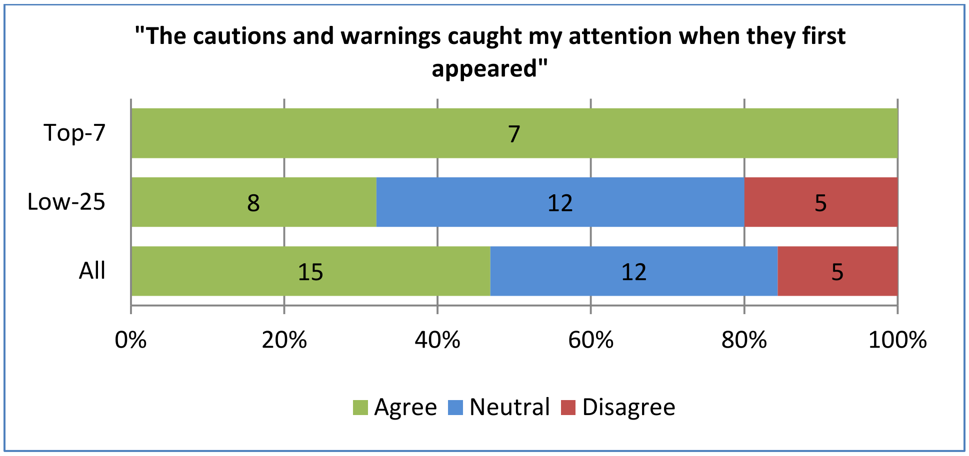
Figure 4-8. Perceived Safety Benefit of the TRP

4.4.1.1.6 Attention-Catching System Cautions and Warning

All of the Top-7 participants agreed that "The cautions and warnings caught my attention when they first appeared." When Low-25 participants were included, the majority (47 percent) still agreed, 38 percent were neutral, and the remaining 16 percent disagreed (Figure 4-9). The only Top-7 comment was "always caught my attention." Low-25 participants who agreed said that the "beeping was very audible" while those who gave neutral responses said that they "noticed them as they used them more" and "louder would be nicer." One participant who disagreed said "too far away," although it is unclear whether this referenced the display screen or the target for which the alert was being issued.



Volpe

Figure 4-9. Ability of the TRP to Catch the Driver's Attention

4.4.1.1.7 Visibility and Understanding of System Cautions and Warnings

In response to the statement "The cautions and warnings were easy to read and understand" theTop-7 participants reported that the display was easily seen from the driver's seat and that the auditory alerts were easily heard (4 Low-25 participants said the display was not easily seen and 6 said that it was not easily heard).

Top-7 participants agreed that the alerts were easy to read and understand, with only one exception who gave a neutral response, commenting that "some displays were too quick to see" (Figure 4-10). The Low-25 participants were once again more mixed, with 50 percent agreeing, 44 percent neutral, and 6 percent disagreeing. The only comment was "training sessions were essential to this!"

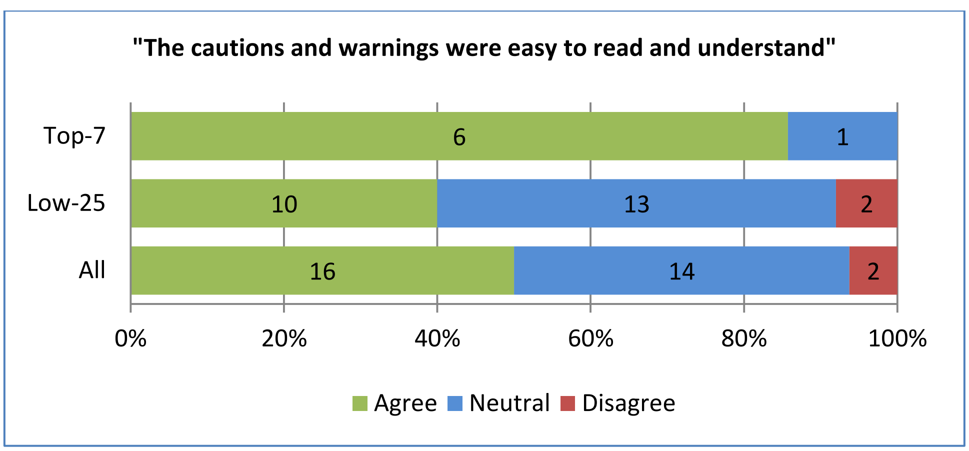


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Figure 4-10. Ease of Reading and Understanding Cautions and Warnings

Another aspect of understanding the TRP system is being able to distinguish the alerts of the different applications and/or each application being able to distinguish between cautions and warnings. To evaluate differences between applications for the system overall, participants were asked to rate their agreement with the statement "It was easy to tell the difference between cautions and warnings for the different applications (i.e., not confusing one application with another)." From the Likert-scale responses only one Top-7 participant disagreed and all the rest agreed.

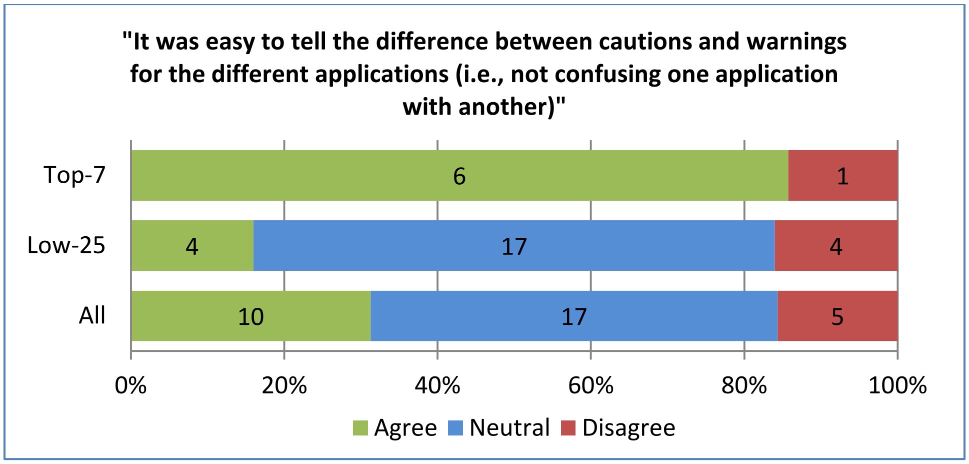

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Figure 4-11. Ease of Distinguishing Between Warnings and Cautions

To evaluate the ease with which participants could distinguish between cautions and warnings for each individual application, participants were asked to rate their agreement with the statement "The difference between a… caution and warning was clearly evident on the display." Agreement tended to vary more between Top-7 participants than within, with Drivers 4, 5, and 23 agreeing for all applications they rated and Drivers 2 and 6 being neutral (Table 4-5). Driver 3 was the only one to mix responses.

Table 4-5. Ease of Distinguishing Between Warnings and Cautions

	Driver ID	FCW	PCW	VTRW	EEBL	CSW
Top-7	**2**	Neutral	Neutral	Neutral	-	-
	3	Disagree	Agree	Disagree	-	Agree
	5	Agree	Agree	Agree	Agree	Agree
	1	-	-	-	-	-
	4	Agree	Agree	-	Agree	-
	6	Neutral	-	-	-	-
	23	Agree	Agree	-	Agree	Agree
Low-25	**-**	1 Agree 4 Neutral 1 Disagree	5 Agree 4 Neutral 3 Disagree	3 Agree 4 Neutral 0 Disagree	1 Agree 5 Neutral 0 Disagree	3 Agree 4 Neutral 2 Disagree

Volpe

4.4.1.1.8 Additional System Training

Another measure of understandability is the amount of training required to use the system. Participants were trained in how to use the system and were then asked if they agreed that "additional training was needed in order to utilize [the application] properly." For all drivers and all applications, the Likert-scale responses were generally "disagree," implying that the training given was adequate (Table 4-6). There were no additional participant comments.

Table 4-6. Need for Additional System Training

	Driver ID	FCW	PCW	VTRW	EEBL	CSW
Top-7	**2**	Neutral	Disagree	-	-	-
	3	Disagree	Neutral	Disagree	-	Disagree
	5	-	Disagree	Disagree	Disagree	Disagree
	1	-	-	-	-	-
	4	Disagree	Disagree	-	Disagree	-
	6	Disagree	-	-	-	-
	23	Disagree	Disagree	-	Disagree	Disagree
Low-25	**-**	1 Agree 3 Neutral 2 Disagree	4 Agree 6 Neutral 2 Disagree	2 Agree 2 Neutral 3 Disagree	1 Agree 3 Neutral 2 Disagree	0 Agree 7 Neutral 2 Disagree

Volpe

4.4.1.1.9 Additional Comments, Suggestions, or Other Observations

In the final question of the survey, participants were asked if they had any additional comments, suggestions, or other observations to share.

Top-7 participant responses included:

- "I realize anything new has to be bested, and perfected."
- "The equipment was easy to use and I think will be beneficial in the future. It has a lot of improving to do but that's why we're doing this."
- "I think everything is a solid idea but hasn't been very valuable since I almost never encountered scenarios that triggered warnings. When things did happen, I felt the passengers saw too much and it made me feel a little embarrassed."
- "The system is great. Thanks you all!"

Low-25 participant responses included:

- "This is a good product just need to know more about it like a class or something."
- "Move the tablet closer to driver. Make alarms louder."

- "If it were in my own vehicle, I would like to be able to modify the alerts (sound volume, etc.) to balance 'desire-to-know' with 'I don't want to be distracted.'"
- "I feel that with more cars equipped with FCW technology, I would get a better feel for it. I rarely came in contact with other vehicles."

4.4.1.2 Individual Safety Applications Versus the Combined Package

Driver acceptance of the TRP as a whole may conceal opinions of individual safety applications. For example, participants may report liking the system overall even though they strongly dislike one particular application. To identify variation in acceptance between individual applications, the IE gauged acceptance for individual applications by the participants' rated desire to have the individual application installed on the buses they drive, based on them agreeing with the statement "I would like [a given application] to be installed on all of the buses that I drive." Instead of including this question in the combined package survey, participants were asked "Overall, I was satisfied with the Transit Safety Retrofit Package."

The Likert-scale responses in these comparisons show little consistency between drivers (Table 4-7, in which participants are rated in descending order based on their rating in the first column). The least-desired application was the FCW and the most-desired the CSW. For Driver 4, a lack of desire for each of the individual applications rated did not preclude the driver from being satisfied with the system overall. For Driver 5, desiring the CSW was not enough to be satisfied with the system overall. The most important result was that the FCW was not desired by most Top-7 participants.

Table 4-7. Ratings of Safety Application Desirability

	Driver ID	All**	FCW*	PCW*	VTRW*	EEBL*	CSW*
Top-7	**23**	Agree	Agree	Agree	-	Agree	Agree
	1	Agree	-	-	-	-	-
	2	Neutral	Disagree	Neutral	-	-	-
	3	Neutral	Disagree	Neutral	Neutral	-	Agree
	4	Neutral	Disagree	Disagree	-	Disagree	-
	6	Neutral	Disagree	-	-	-	-
	5	Disagree	Disagree	Neutral	Neutral	Neutral	Agree
Low-25	**-**	6 Agree 18 Neutral 1 Disagree	2 Agree 3 Neutral 1 Disagree	2 Agree 5 Neutral 5 Disagree	1 Agree 5 Neutral 1 Disagree	1 Agree 5 Neutral 0 Disagree	1 Agree 5 Neutral 3 Disagree

*** "Overall, I was satisfied with the Transit Safety Retrofit Package."*

** "I would like [this application] to be installed on all of the buses that I drive."*

Volpe

4.4.1.3 FCW

Driver 1 reported not receiving any FCW warnings and did not answer any questions about the FCW system.

There was little praise for the FCW, which was criticized for providing nuisance alerts, being distracting, and for providing alerts that were visible to passengers and so might panic them. Even the question asking what participants liked the most generated primarily negative remarks (Table 4-8). One Low-25 participant suggested the system be changed so it had the “ability to sense all vehicles, not just specially equipped ones.”

Table 4-8. FCW Features Top-7 Participants Liked Most/Liked Least/Would Change

Driver ID	Liked Most	Liked Least	Changes?
2	“None”	“None”	-
3	-	“Didn’t like it at all. The system would warn even when I had a full control and was adjusting to right or left of vehicle in front”	“Don't like this application”
5	“Showed the FCW and I wasn't anywhere (anywhere) near a rear end collision”	“Distracting when that's not really happening”	“Good app. if working properly”
1	-	-	-
4	“I was already slowing down prior to the warning. There was a lag in the system”	“The lane accuracy”	-
6	“I didn't really like [it] much. I suppose the idea is likeable though”	“It made everyone on the bus think I was about to rear end the vehicle in front of me. The system isn't discrete”	“Everything is too visible to the public and people panic easily”
23	“It's alert!”	-	-

Volpe

Overall, even though Likert-scale responses fromTop-7 participants were that the system was generally easy to use and understand, most did not want to have the application in the buses they drove (Table 4-9). The two drivers who reported receiving incorrect alerts the most frequently provided the most negative criticism.

Table 4-9. Ratings of FCW for Top-7 Participants Individually and for Low-25 Summarized

Driver ID	2	3	5	1	4	6	23	Low-25*
It was clear why FCW was issued	Neutral	Disagree	Disagree	-	Neutral	Neutral	Agree	2-4-0
I trusted the FCW	Disagree	Disagree	Disagree	-	Neutral	Neutral	Agree	1-5-0
The FCW was effective at drawing attention	Neutral	Disagree	Disagree	-	Neutral	Agree	Agree	1-4-1

Driver ID	2	3	5	1	4	6	23	Low-25*
The FCW was easy to use and understand	Neutral	Agree	Agree	-	Agree	Agree	Agree	3-3-0
I would like FCW on the buses I drive	Disagree	Disagree	Disagree	-	Disagree	Disagree	Agree	2-3-1
Frequency of incorrect FCW	Every few shifts	Multiple times per shift	Multiple times per shift	-	Every few shifts	Very rarely	Very rarely	-

** Values are for Agree-Neutral-Disagree*

Volpe

4.4.1.4 PCW

Drivers 1 and 6 reported not receiving any PCW warnings and did not answer any questions about the PCW system.

Unlike the FCW, a Top-7 driver praised the PCW for its accuracy and ability to draw the driver's attention to the crosswalk (Table 4-10). Nonetheless, the application was still criticized for providing false alerts and one participant suggested an auditory voice alert. A Low-25 participant suggested improvements to system "accuracy and [to] not [be] so distracting to the driver."

Table 4-10. PCW Features Top-7 Participants Liked Most/ Liked Least/Would Change

Driver ID	Liked Most	Liked Least	Changes?
2	"It was accurate"	"None"	"Make it talk"
3	"Drew my attention to the crosswalk"	"Still getting false positives on cars passing through the target area"	"Still have to eliminate car readings. Did get a lot when pedestrians were present"
5	"Safety"	"Being applied at the wrong time"	"Good app. if working properly"
1	-	-	-
4	-	"Warning was incorrectly given for the lane I was in"	-
6	-	-	-
23	"It works every time someone presses a button at the light"	-	-

Volpe

The Likert-scale responses praise the PCW application for its ability to effectively draw attention and for being easy to use and understand (Table 4-11). Desire for the application was nonetheless mostly neutral.

Table 4-11. Ratings of PCW Participants Individually and for Low-25 Summarized

Driver ID:	2	3	5	1	4	6	23	Low-25*
It was clear why PCW issued *caution*	Agree	Disagree	Disagree	-	Neutral	-	Agree	5-7-0
It was clear why PCW issued *warning*	Agree	Disagree	Disagree	-	Neutral	-	Agree	6-5-1
I trusted the PCW	Agree	Disagree	Disagree	-	Disagree	-	Agree	5-6-1
The PCW was effective at drawing attention	Agree	Agree	Agree	-	Neutral	-	Agree	4-7-1
The PCW was easy to use and understand	Agree	Agree	Agree	-	Agree	-	Agree	5-6-0
I would like PCW on the buses I drive	Neutral	Neutral	Neutral	-	Disagree	-	Agree	2-5-5
Frequency of incorrect PCW	-	Multiple times per shift	Multiple times per shift	-	Every few shifts	-	Multiple times per shift	

** Values are for Agree-Neutral-Disagree*

Volpe

4.4.1.5 VTRW

Drivers 1, 4, 6, and 23 reported not receiving any VTRW warnings and did not answer any questions about the VTRW system. Driver 2 also reported not receiving any VTRW warnings but did answer some of the questions.

The VTRW received very little feedback and responses were neutral. One participant thought it had potential but was too slow, and another thought it raised attention for the left mirror but needed to work better (Table 4-12). One of 2 Low-25 participants who reported receiving VTRW alerts suggested the application be changed; “The system would be better served to use a camera feed, perhaps with highlighting and warning sounds. The feed can be set up in the driver's blind spot on the driver's side of the vehicle.”

Table 4-12. VTRW Features Top-7 Participants Liked Most/Liked Least/Would Change

Driver ID	Liked Most	Liked Least	Changes?
2	-	-	-
3	“It has potential could be very useful in other applications”	“It didn't seem to warn fast enough”	“It should be used often if it could warn of cars to the left of the bus at any time”
5	“Made me check out my left mirror”	“Loved this app.”	“To work properly”
1	-	-	-
4	-	-	-
6	-	-	-
23	-	-	-

Volpe

Likewise, there was very little feedback from the Likert-scale responses and no consensus (Table 4-13).

Table 4-13. Ratings of VTRW Participants Individually and for Low-25 Summarized

Driver ID:	2	3	5	1	4	6	23	Low-25*
It was clear why VTRW issued *caution*	Neutral	Disagree	Neutral	-	-	-	-	2-4-1
It was clear why VTRW issued *warning*	Neutral	Disagree	Neutral	-	-	-	-	3-3-1
I trusted the VTRW	-	Neutral	Neutral	-	-	-	-	1-4-2
The VTRW was effective at drawing attention	-	Neutral	Agree	-	-	-	-	2-5-0
The VTRW was easy to use and understand	-	Neutral	Agree	-	-	-	-	2-5-0
I would like VTRW on the buses I drive	-	Neutral	Neutral	-	-	-	-	1-5-1
Frequency of incorrect VTRW	-	Very rarely	Once per shift	-	-	-	-	-

** Values are for Agree-Neutral-Disagree*

Volpe

4.4.1.6 EEBL

Drivers 2, 3, 1, and 6 reported not receiving any EEBL warnings and did not answer any questions about the EEBL system.

Like the VTRW, there was very little feedback for the EEBL application (Table 4-14). Top-7 participants praised its functionality and safety potential, but criticized it for being occasionally distracting and for providing alerts late. A Low-25 participant remarked that the application is "redundant with the FCW, or alternatively, could be treated as an extension of the FCW." Otherwise no changes were suggested.

Table 4-14. EEBL Features Top-7 Participants Liked Most/Liked Least/Would Change

Driver ID	Liked Most	Liked Least	Changes?
2	-	-	-
3	-	-	-
5	"For safety"	"Distracting sometimes"	-
1	-	-	-
4	-	"It warned me after I already reacted"	-
6	-	-	-
23	"It works"	-	"None"

Volpe

Likert-scale responses towards the EEBL varied more by participant than question, with two mostly neutral and one entirely positive (Table 4-15). The exception was for ease of use and understandability, which was praised by all three participants.

Table 4-15. Ratings of EEBL Participants Individually and for Low-25 Summarized

Driver ID:	2	3	5	1	4	6	23	Low-25*
It was clear why EEBL was issued	-	-	Neutral	-	Neutral	-	Agree	2-4-0
I trusted the EEBL	-	-	Neutral	-	Neutral	-	Agree	0-6-0
The EEBL was effective at drawing attention	-	-	Neutral	-	Neutral	-	Agree	2-4-0
The EEBL was easy to use and understand	-	-	Agree	-	Agree	-	Agree	3-3-0
I would like EEBL on the buses I drive	-	-	Neutral	-	Disagree	-	Agree	1-5-0
Frequency of incorrect EEBL	-	-	Every few shifts	-	Very rarely	-	Every few shifts	-

** Values are for Agree-Neutral-Disagree*

Volpe

4.4.1.7 CSW

Drivers 1, 4, and 6 reported not receiving any CSW warnings and did not answer any questions about the CSW system. Driver 2 did not report either receiving or not receiving any CSW warnings and also did not answer any questions about the warning.

The CSW was rated by only 3 Top-7 participants, but all 3 praised its accuracy and usefulness (Table 4-16). Changes suggested by two Low-25 participants were to “add ability to edit suggested/preferred curve speed” and “as noted before, allow for adjustments by operator, or based on road conditions. Warnings become much more appropriate in rain/snow/darkness.”

Table 4-16. CSW Features Top-7 Participants Liked Most/Liked Least/Would Change

Driver ID	Liked Most	Liked Least	Changes?
2	-	-	-
3	“It came on at the right time. Worked the best of all of the applications”	“Nothing”	-
5	“Work correctly a lot of times”	“Have no complaints”	“This feature would help strongly in winter months.”
1	-	-	-
4	-	-	-
6	-	-	-
23	“It tells you and shows you the curb”	-	-

Volpe

Likert-scale responses were also unanimously positive for all criteria by all 3 of the Top-7 participants (Table 4-17). Even Driver 23, who reported receiving incorrect alerts "multiple times per shift," was positive (although it should be pointed out that Driver 23 was positive fairly consistently throughout the survey).

Table 4-17. Ratings of CSW Participants Individually and for Low-25 Summarized

Driver ID:	2	3	5	1	4	6	23	Low-25*
It was clear why CSW was issued	-	Agree	Agree	-	-	-	Agree	4-4-1
I trusted the CSW	-	Agree	Agree	-	-	-	Agree	2-5-2
The CSW was effective at drawing attention	-	Agree	Agree	-	-	-	Agree	5-3-1
The CSW was easy to use and understand	-	Agree	Agree	-	-	-	Agree	4-5-0
I would like CSW on the buses I drive	-	Agree	Agree	-	-	-	Agree	1-5-3
Frequency of incorrect CSW	-	Never	Every few shifts	-	-	-	Multiple times per shift	-

** Values are for Agree-Neutral-Disagree*

Volpe

4.4.1.8 Privacy

There was no indication that participants had strong concerns that the applications package could be used to monitor their driving patterns (Figure 4-12). Among Top-7 participants, replies were mostly evenly distributed, with 3 participants giving neutral ratings and 2 having agreed and 2 disagreed. For all participants, 50 percent were neutral, 31 percent disagreed, and only 19 percent agreed.

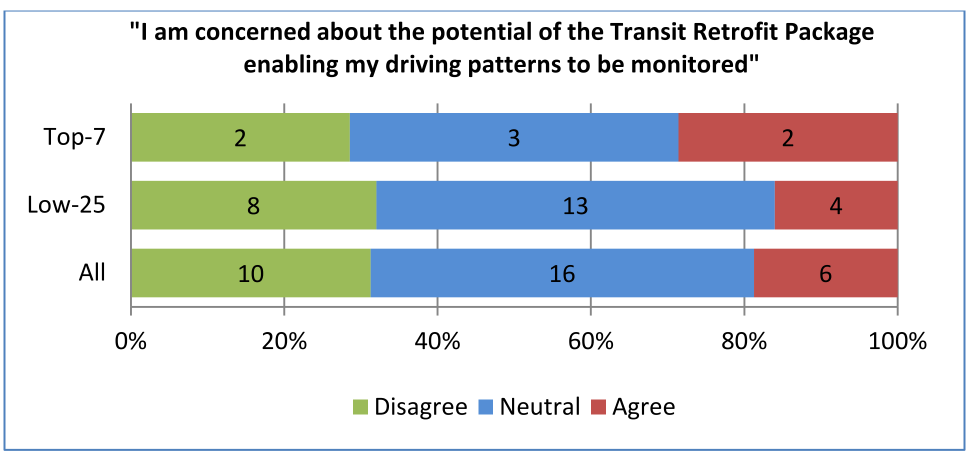

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Figure 4-12. Ratings of Concerns Over Monitoring Driving Patterns

In terms of privacy from the passengers, 5 Top-7 participants reported that passengers noticed and commented on the system. One participant said this implied to the passengers that the driver was doing something wrong (Table 4-18). Only 3 Low-25 participants reported comments from passengers, all asking what the system was.

Table 4-18. Comments by Passengers Reported by Top-7 Participants

Driver ID	"Did any passengers comment on warnings?" "If so, what were their comments?"	
2	Yes	"What is that?"
3	Yes	"They asked mostly what the equipment was."
5	Yes	"Wondered what it was."
1	No	-
4	Yes	"Asked about the tablet itself, not about the warnings."
6	No	"Everyone thought I was doing something wrong when a warning would occur."
23	Yes	"'What is that?' Then I would explain it and they think it's a cool system."

Volpe

4.4.1.9 Unintended Consequences

Participants were mostly neutral about how distracting the cautions and warnings could be (Figure 4-13). Five out of 7 (71 percent) Top-7 participants were neutral as were 59 percent of all participants. The only descriptive comment by a Top-7 participant was "false readings," given by Driver 3, who gave a neutral rating. Comments among the Low-25 participants included complaints that one had to look away from the road for too long and a clarification that the system cautions and warnings were distracting, "unless you already know what [the warning is for] before it goes off."

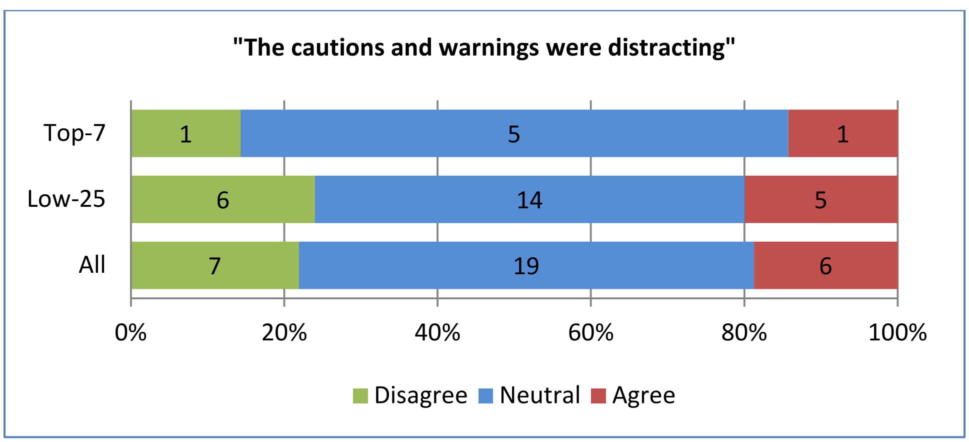

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Figure 4-13. Ratings of Distractibility from Cautions and Warnings

Distractibility of cautions and warnings was more directly addressed by the next question, which asked "Monitoring or interpreting the TRP cautions and warnings was no more distracting than using other driving equipment." Five out of 7 (71 percent) Top-7 participants agreed that it was not, with one (14 percent) neutral and 1 (14 percent) disagreeing (Figure 4-14). For all participants, agreement went down to 41 percent; equal to the percent of neutral responses, though still greater than the 19 percent who disagreed. There were no clarifying comments made by any of the participants.

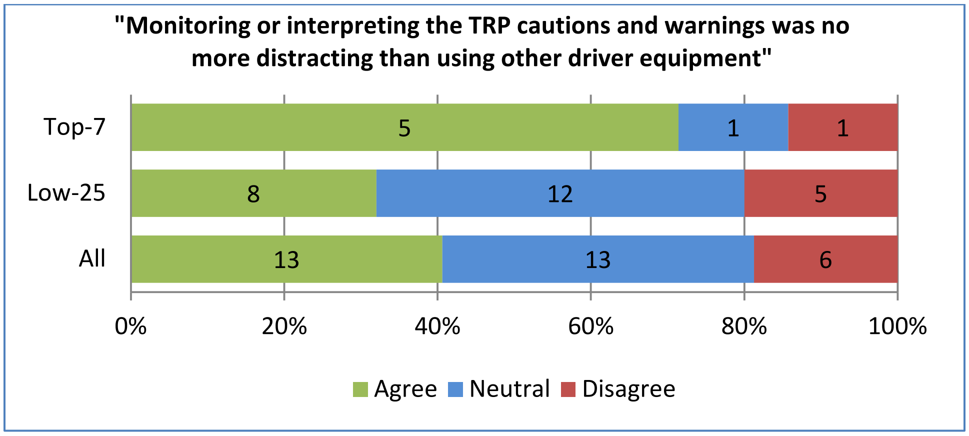

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Figure 4-14. Ratings of Distraction from Cautions and Warnings Compared to Other Driver Equipment

Participants were asked to report any changes they noticed in their own driving behavior (Table 4-19). Only 2 Top-7 participants noticed changes: Driver 3 reported being more cautious after receiving an alert and driving differently to prevent alerts. Driver 23 reported becoming more aware of driving situations that could cause an alert and driving more cautiously after receiving them. Six Low-25 participants reported changes (only checking one box each).

Table 4-19. Reported Changes in Driving Behavior

"What behaviors do you think changed as a result of having the TRP technology in your bus? *(check all that apply)*"	Top-7		Low-25	
	Number of Responses	Percent of Top-7 Participants	Number of Responses	Percent of Low-25 Participants
"I became more aware of driving situations that could cause a caution or warning"	1	14%	5	20%
"I was more cautious after receiving a caution or warning"	2	29%	0	0%
"I started to pay less attention because I relied on the cautions and warnings"	0	0%	0	0%
"I drove differently to prevent the system from warning me"	1	14%	1	< 1%
Other	0	0%	0	0%

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4.4.2 Redeployment

For the Redeployment, 27 participants filled out surveys. Four of these participants (Drivers 2, 5, 6, and 23) were Top-7 participants from the Model Deployment. Nine were Low-25 participants, and the remaining 14 did not have hours or survey results from the Model Deployment. As before, the number of participants used in each analysis may be slightly smaller than 27 because participants often left questions on the surveys blank.

Fewer types of analyses could be conducted for the Redeployment test period than for the Model Deployment test period due to the smaller number of participants and the fact that the Redeployment survey did not include as many questions as the Model Deployment survey. Results in this section focus on feedback about changes made to the TRP applications.

4.4.2.1 General Impressions

This subsection describes overall impressions of the combined suite of safety applications.

4.4.2.1.1 Most and Least Liked Aspects of the System

When asked what they most liked about the system, several participants mentioned changes from the Model Deployment:

- “Better display” (by Driver 2)
- “Audio alerts—that way I don’t have to look to know”
- “The updated images are much more relevant, and the voice updates are clearer to discern what is/may be going on in traffic”
- “Not as obtrusive”
- “Some of the bugs were worked out to improve the system.”

Participants made fewer remarks about what they liked least. False or nuisance alerts were mentioned several times and there were several comments over issues with the screens:

- “Forward collision warnings were too frequent and usually didn’t apply”
- “Need more options on screen”
- “Sometimes found the display to be distracting when it switched screens”
- “The distraction”
- “Not a big fan of having a tablet in the driver's area—somewhat distracting”
- “False or incorrect signals”

Two participants noted difficulties with hearing the auditory warnings and another with seeing the screen in harsh sunlight.

4.4.2.1.2 Impact on Job Performance

It was not clear whether the perceived impact of the system on job performance changed from Model Deployment to Redeployment, although at least one Top-7 driver increased from a “negative” to “positive” (Table 4-20). Other remarks included complaints about the screen being bright and distracting at night and also several remarks that it made driving safer and improved awareness. One participant noted that "Pro: Audible warnings may be good when a driver may be tired, or is simply not in the habit of looking ahead or scanning well. Also may verify to passengers what may be occurring that the driver was forced to react to, thus explaining a hard stop, swerve, etc. Con: Could be thought of as a distraction for some drivers, 'something else to pay attention to.'"

Table 4-20. Impact of TRP on Job Performance by Top-7 Participants

Driver ID	Model Deployment	Redeployment
2	"Negatively—makes you turn your head in wrong direction"	"Positive-more 'eyes' on the road"
6	"I generally forgot it was doing anything until I'd approach another vehicle with the system. In those instances I usually found it a little overwhelming because I was never close to rear ending a vehicle but the system made it feel that way"	"Neutral experience. I rely on my own abilities more than this additional tech."
23	"It helps when someone is crossing the street"	"It's like another eye!"

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4.4.2.1.3 Perceived Increase in Driving Safety

The Redeployment appeared to have a positive effect on agreeing with the statement that the system increased driving safety (Figure 4-15, which compares all drivers in the Model Deployment to all drivers in the Redeployment). Even though the percentage of participants with a neutral opinion stayed the same, the percentage of participants who agreed with the statement increased from 16 to 39 percent, while the percentage of participants who disagreed decreased from 38 to 13 percent. This change was statistically significant, increasing from a median score of 4 (IQR: 3) to 5 (IQR: 3) *(Mann-Whitney between-subjects test*, $U = 236.5$, $n_{MD} = 32$, $n_{RD} = 23$, $p = .023$). Furthermore, in all cases where participants gave responses for both Model Deployment and Redeployment surveys, their ratings either stayed the same or positively increased. There were no comments directly addressing this increase in driving safety.

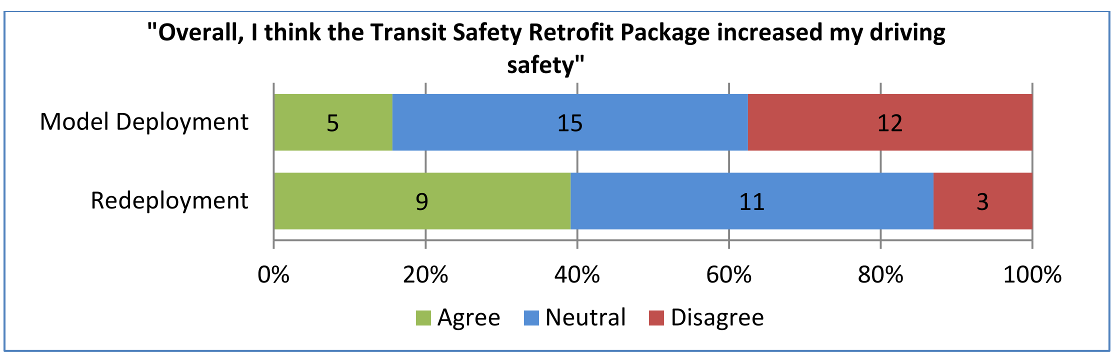

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Figure 4-15. Ratings of Perceived Safety Benefits from the Safety Package During Redeployment

4.4.2.1.4 Visibility and Understanding of System Cautions and Warnings

Similar to the Model Deployment, all participants reported that the display was easily monitored from the driver's seat. The survey asked the following questions about improvements during the redeployment (for the first three bullets, responses were counted only for the 13 participants with experience in both the Model Deployment and the Redeployment):

- "Did the repositioning of the Tablet from the [Model Deployment] improve your ability to monitor the Tablet? Yes or No." Nine out of 13 participants (69 percent) said yes, including 3 out of 3 Top-7 participants.
- "Did you prefer the voice-based audio alerts used in [the Redeployment] or did you prefer the tone-based audio alerts used in [the Model Deployment]?" Nine out of 13 participants (69 percent) preferred the voice-based alerts, including 3 out of 3 Top-7 participants.
- "Did you find it easier to identify what type of warning was being presented with the extended display time? (Display stayed on longer after a warning) Yes or No." Nine out of 13 participants (69 percent) said yes, including 3 out of 3 Top-7 participants.
- "Was the extended time sufficient to determine what was being displayed or would you have preferred it remained on the display longer after a warning?" Seventeen out of 22 (including 1 Top-7 participants) answered "Sufficient time to identify warning type" (77 percent) and 5 (including 2 Top-7 participant) answered "Would like display to remain on longer after a warning to help me identify the warning type" (23 percent)

Participant ratings of how easy it was to tell the difference between different applications increased from the Model Deployment to the Redeployment test period (Figure 4-16). The percentage of all participants who agreed that it was easy to distinguish the alerts increased from 31 to 50 percent, and the number who disagreed decreased from 16 to 0 percent. This change was statistically significant, increasing from a median score of 4 (IQR: 3) to 5.5 (IQR: 3) *(Mann-Whitney between-subjects test*, U = 231.0, n_{MD} = 32, n_{RD} = 22, p = .030). Furthermore, in all but one cases where participants gave responses for both Model Deployment and Redeployment surveys, their ratings either stayed the same or increased. No comments addressed the change directly.

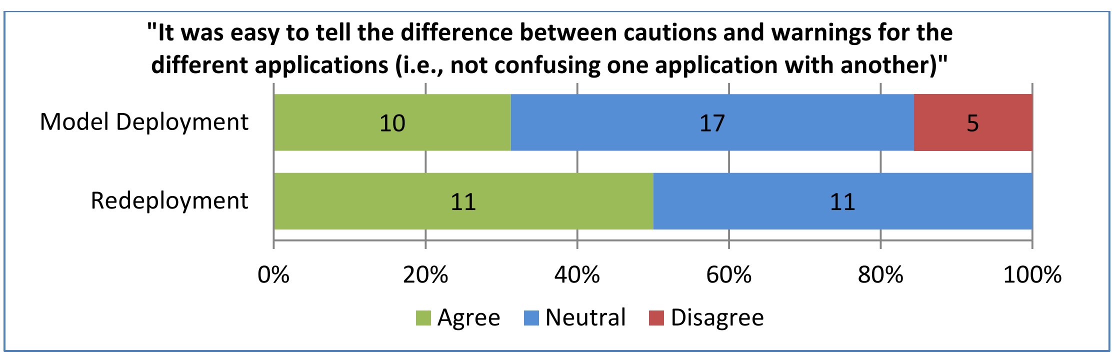

Figure 4-16. Ratings of Easily Distinguishing Between Safety Application Alerts During Redeployment

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4.5 Focus Group Results

This subsection presents the results of the focus groups broken down by Model Deployment and Redeployment.

For the Model Deployment there were five participants in the focus group, four of which were Top-7 drivers, including the two with the most experience using the system. For the redeployment there were a total of three participants, all of which were Top-7 drivers and two of which had taken part in the Model Deployment focus group as well.

Both focus groups took place at UMTRI after the participants had finished using the TRP-equipped buses. For the Model Deployment, the focus group was conducted on September 30th, 2013, and for the Redeployment on March 18th, 2014.

4.5.1 Model Deployment

4.5.1.1 General Impressions

When asked how they would respond if they had to choose between having the system or not, 3 participants said definitely no, and 2 seemed neutral.

One participant suggested linking the system with emergency vehicles: "I think what would make it desirable may be if it interacted with emergency vehicles, because a lot of times you'll come around a curve on Fuller [Road] at night, and sometimes I don't notice that there's a cop who pulled over a car…Or if there's an ambulance behind you, you don't know it but you can just hear it somewhere."

4.5.1.2 FCW

Most participants viewed the FCW as more of a nuisance than a help. There was also little awareness of the difference between cautions and warnings.

Participants were asked about the three potential locations of remote vehicles: directly in front, one lane over, or farther downstream. When asked whether it was helpful to distinguish each of these cases to the drivers and whether there should just be one general FCW, one participant suggested that on the highway alerts could be issued for vehicles that are further away, but in the city alerts would be only for vehicles that are closer. Another participant suggested using the FCW as a training tool for new bus drivers because experienced professional drivers know how much of a lead distance to give the vehicles in front.

Participants said they even though there were no occasions when somebody ahead was braking and they did not receive an FCW (false negatives) they had little to no trust in the FCW (or the EEBL).

Participants were willing to try a newer version of the FCW on their bus if the system was improved.

4.5.1.3 PCW

Participants were asked if they were able to understand what the PCW application was trying to tell them. One participant said yes and a few others said that they received multiple false positive PCW alerts. One participant stated that the system alerted him to the presence of his own vehicle while driving through the intersection.

Participant feedback on usefulness included: “It was useful in the respect to the fact that when [the pedestrian] pushed the [crosswalk] button, it actually worked. And when we were testing it originally we had a thousand million false positives, and it still was happening after that, not as frequently but it still happened. So there was, more or less, it got better but it didn’t get good enough. And the yellow warning is probably your best bet, but then it’s a human interaction. How are we going to get this guy to push the dang button to walk across the street? But it did make me pay attention. I wanted to see if it was working because of all the issues we had with it, and it worked a lot more than originally with all the cars, but it did at some point have issues with the cars too.”

Participants suggested that the system would be better if every pedestrian had to push the crosswalk button when they intended to cross the intersection. They also generally agreed that they trusted the PCW alerts. However, they generally disagreed about whether the system would be useful if it was implemented in all University of Michigan fleet buses.

4.5.1.4 VTRW

None of the participants actually received a VTRW warning, but they nonetheless liked the idea of it and thought it could be the most helpful of the applications.

4.5.1.5 EEBL

Participants were asked if they could distinguish between EEBL and FCW warnings. Responses were mostly negative, saying the screen flashed too quickly for them to tell the difference. One participant suggested that the tablet screens should have a history so they could go back and look at previous alerts.

Participants were asked if it mattered whether or not they knew whether it was an FCW or EEBL that they had received. They generally felt it did not because in either case they had reacted to the sound of the alert before they had even looked at the screen.

4.5.1.6 CSW

Participants reported that they generally did not make an effort to distinguish between cautionary alerts and warnings for CSW, but most reported not receiving any CSWs at all. One participant reported receiving a CSW from not paying attention and driving too fast. Participants did not think that CSW alerts were helpful, but that they could be if they were more widely implemented.

Participants were asked if there were times they felt like they were going fast enough to have triggered an alert but they did not receive one (a false negative). A few replied that this had happened at least once.

4.5.1.7 Privacy

One participant was apprehensive about data collection because he was fearful that insurance companies would be able to acquire the data and use it to raise insurance rates. Several shared this concern. Others were fearful of “hacking.”

Participants were asked if passengers had any reaction to the system and if so, what kind of reaction. Most participants stated that passengers were merely curious when alerts were issued. One participant said that he told curious riders to Google “UMTRI Safety Pilot.” One participant didn’t have any curious riders. Most participants mentioned that riders were more curious about the tablet than the alerts.

4.5.2 Redeployment

To avoid redundancy, this subsection only includes focus group responses addressing the changes (or lack of changes) from the Model Deployment to the Redeployment test periods.

4.5.2.1 General Impressions

4.5.2.1.1 False Warnings and Trust in the System

Participants reported little trust in the system due to false warnings. They said that they had to always look at the warnings themselves—believing their judgment to be more important than the system—and that relying solely on the warnings was dangerous.

All participants said they would have the system turned off if they could. If effort was needed to remove the system (i.e., if the bus driver needed to insist on its removal) participants reported they did not care either way ("I feel neutral towards it"). Recommended changes to increase interest in warnings included the ability to switch off the system and expanding crosswalk systems into more areas with pedestrians.

4.5.2.1.2 Full Market Penetration

When asked if the system would be useful if all vehicles on the road were equipped with V2V, participants agreed that it would be useful but thought that full-market penetration is "not really realistic." Participants thought that technology "would be more useful for regular-car-to-regular-car warnings." Since they are professional drivers they are already aware of some of the issues the warnings designed to address.

4.5.2.1.3 Visual Display

Participants reported that the visual display was located in a good, unobtrusive spot, but said that unless the bus was loud, they generally heard the auditory alert first. They often looked to the screen to confirm the warning and to see what type of warning was issued. As one participant said, "the key is to confirm—looked at the display to see the warning and then confirm that it was actually happening [which often times it wasn't]." Participants noticed and appreciated the increased display time for warnings, particularly for the PCW, but not for the EEBL.

Two of the 3 participants in the focus group reported that their tablet only worked intermittently. For one of these participants, the tablet functioned only half the time—it would start working and then switch off. The third participant reported no such problems.

4.5.2.1.4 Verbal Warnings

Participants provided feedback on the verbal warnings that replaced the warning tones. Two of the 3 participants reported they could hear that an alert was being issued, but were unable to hear the words over the noise level of the bus, even when the system volume was set to its highest level. The third participant reported no problems in understanding the verbal warnings and thought they were an improvement "because it actually gives you an idea of what to look for. If the voice says 'Pedestrian in walkway,' you look over to see if it's accurate." Of the two participants who could not understand the verbal warnings, one thought it didn't matter if a tone or a verbal warning was used, and the other preferred the verbal warning.

4.5.2.1.5 Perceived Increase in Driving Safety

As reported in Section 4.4.2.1, participants reported that warnings came after they were already aware of the situation. In general, participants did not report receiving warnings that provided a safety benefit, although one participant said that the PCW was useful when a car was blocking the view of the crosswalk and the pedestrian was crossing at a time when they should not have. The FCW was not considered helpful by all three participants. One participant was very annoyed at receiving repeated warnings off and on when driving alongside an equipped vehicle.

Overall in the focus group, the system was not seen as sufficiently beneficial to be installed on more buses. One exception was less-experienced drivers, who might benefit from the PCW, especially in bigger cities with more complex and aggressive driving. Even for inexperienced drivers, the FCW was not seen as adding value.

The blind spot was considered to be important and a warning for the blind spot would be useful for making right turns.

4.5.2.2 FCW

The FCW was again regarded as annoying and of little help by the participants in this focus group.

4.5.2.3 PCW

Participants reported fewer false-positive warnings with the PCW alert during the Redeployment compared to the Model Deployment. Sometimes false warnings were believed to be caused by cars in the crosswalk instead of pedestrians. One participant reported losing trust in the system, but still looking, i.e., not ignoring the alerts. The participant also reported the system providing something of “an entertainment factor.” All drivers reported the alerts ceasing after passing the crosswalk.

PCW warnings were said to be more useful around the student area than the medical area because the students are “more unruly.” Another countered that “the warning wouldn’t be helpful in more populated areas because the warning light would be on all the time, and wouldn’t be as effective.” Nonetheless, participants believed the PCW would be more useful in bigger cities since there is “not that much traffic in Ann Arbor” and in general there is “not a lot of benefit for small communities.”

4.5.2.4 VTRW

Even if it worked with every car on the road, the VTRW was not considered to be useful in Ann Arbor, but could be more useful in bigger cities where taxis could cut the driver off.

4.5.2.5 EEBL

Participants reported not being interested in an EEBL warning of events one lane over, with the exception of their blind spots. They likewise said they were not interested in knowing if a car two cars ahead hit its brakes hard, saying there would be no real benefit to that.

4.5.2.6 CSW

To make the CSW more effective, participants suggested adding it to locations that drivers are not familiar with, since they know the curves on their routes well. Furthermore, “the warning would have to come much earlier than it does. The warning would have to more or less describe the curve and warn that it was coming before you are in it. Because by the time you are in the curve, it becomes a control issue." It would be more effective if it was preventative.

4.5.2.7 Privacy

Responding to privacy concerns about where the bus is going or at what speed, one participant said, "I don't care too much about privacy," and another reported little concern about privacy, guessing that it might be because that participant was younger than the others. The third participant said, "my concern is that somehow maybe someone will be able to hack the system and be able to tell when the drivers are doing something they shouldn't be doing and raise their insurance rates."

5 Conclusions

Overall, the Safety Pilot Model Deployment demonstrated that TRP safety applications can be deployed in a real-world driving environment. The experimental design created naturalistic interactions between the TRP buses and other DSRC-equipped vehicles and infrastructure, and the safety applications issued warnings in the safety critical driving scenarios that they were designed to address.

The Model Deployment was also crucial in revealing areas for improving the performance of the prototype safety applications, which could not have been identified in controlled testing environments. Some of these improvements were implemented and tested during the Redeployment test period, while others require future research.

This section presents key findings from the TRP Safety Pilot Model Deployment evaluation. Findings are separated into three categories; system performance, safety impact, and driver acceptance.

5.1 System Performance

The most critical area for improvement in the V2V and V2I prototype safety applications is properly determining the relative location of remote vehicles and/or determining the absolute location of the host vehicle with lane-level accuracy. This impacted the FCW, VTRW, and PCW safety applications, since these applications use relative lane level position as part of the application warning logic. Position accuracy is impacted by many factors; including GPS accuracy, the timeliness and accuracy of the messages received from the remote vehicle, road geometry, and the application software.

Key findings for each application are summarized in Table 5-1 and detailed in the subsections below.

Table 5-1. System Performance Conclusion Summary

Safety Application	Conclusions
FCW	41 % of alerts issued for in-path targets (valid alerts)
CSW	57 % of alerts issued when TRP was approaching or in the curve (valid alerts) Accuracy much higher for north approach than for east approach 22 potential missed alerts observed
EEBL	Over 90% of alert issued for targets on same road (valid alerts)
PCW	Accuracy of PCW doubled from Model Deployment to Redeployment (12% valid to 24% valid) Percent of alerts that address the safety need doubled from the Model Deployment to the Redeployment (9% to 18 %)
VTRW	In the Model Deployment, 14 % of cautionary and 22% of imminent alerts were issued when

Safety Application	Conclusions
	the target followed the prescribed path (valid alerts) VTRW performance improved during the Redeployment in terms of alerts being issued when drivers were intending to proceed

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5.1.1 FCW

- Overall, 41 percent of FCW alerts were issued for in-path remote vehicles (true alerts).
- FCW alerts issued for moving remote vehicles were more accurate than FCW alerts issued for stopped remote vehicles (53 percent of moving targets were in-path, while 23 percent of stopped targets were in-path).
- Sixty percent of FCW alerts triggered by other TRP buses were in-path, whereas only 38 percent of FCW alerts issued for all other target types were in-path. This result is likely due to the travel patterns of the TRP buses and the likelihood of the other TRP buses being in the same lane as the host vehicle.
- The IE observed 4 scenarios that appear to be missed FCW alerts during the Model Deployment field test. With full deployment it is likely that missed FCW alerts would be more common. Three of the potential missed FCW events occurred when the host vehicle was traversing a curve, suggesting that curved road scenarios may impact the applications' ability to properly identify a relevant remote vehicle.

5.1.2 CSW

- Fifty-seven percent of CSW alerts were issued when the TRP was either entering or traversing the equipped curve (true alerts).
- All CSW alerts issued when the TRP bus was making a right turn on the Bonisteel Boulevard equipped curve were true alerts, whereas only 36 percent of the alerts issued when the TRB bus was making a left turn on the Bonisteel Boulevard equipped curve were true alerts. This result suggests that the CSW application software could be improved by modifying the logic to accommodate both travel directions.
- The IE observed 22 missed CSW alert scenarios during the Model Deployment field test. Missed CSW alerts could be caused either by errors in the safety application software, or by the reliability of CSW infrastructure.

5.1.3 EEBL

- The IE observed only 27 EEBL alerts during the Model Deployment field test. Over 90 percent of these alerts were true alerts.

5.1.4 PCW

- The performance of the PCW improved based on the modifications made prior to the Redeployment test period.

  - During the Model Deployment test period, 12 percent of PCW alerts where the presence of a pedestrian could be confirmed satisfied the design criteria. This percentage doubled during the Redeployment test period.
  - Twenty percent of the PCW alerts during the Model Deployment were issued when the bus went straight through the intersection (did not traverse the equipped crosswalk). During the Redeployment only nine percent of alerts were issued when the TRP bus went straight through the intersection.
- When considering only the alerts where the presence of a pedestrian could be confirmed, only eight percent of the PCW alerts during the Model Deployment and 18 percent of the PCW alerts during the Redeployment were issued for scenarios that satisfied the warning criteria and could potentially help the driver avoid hitting a pedestrian. The PCW application could be improved by tailoring the timing of the warnings so that they are issued only when the driver is proceeding, or about to proceed into the equipped crosswalk. In other words, warnings should be suppressed in driving scenarios where the information provided by the warning is not useful to the driver (e.g., the bus was approaching a red light).

5.1.5 VTRW

- During the Model Deployment test period, 14 percent of the cautionary VTRW alerts and 22 percent of the imminent VTRW alerts were issued in scenarios where the remote vehicle followed the prescribed path.
- False VTRW alerts were primarily caused by inaccurate relative positioning of the remote vehicle. Since the VTRW application relies on lane-level positioning accuracy, misplacing the remote vehicle target leads to false alerts. The VTRW application would benefit from improved relative positioning.
- The VTRW application improved in terms of alerts being issued when drivers were departing, or planning to depart from the bus stop. Forty-five percent of Model Deployment VTRW alerts were issued when the bus driver was intending to depart the bus stop, and 86 percent of Redeployment VTRW alerts were issued when the bus driver was intending to depart the bus stop. Overall three percent of Model Deployment VTRW alerts and zero percent of Redeployment VTRW alerts were issued in scenarios that met the design criteria and could potentially help the driver avoid hitting a right turning vehicle.
- The IE observed two potential missed VTRW alert scenarios during the field test. In both events the driver had the brake engaged for most of the event, and then released the brake as the remote vehicle reached the front of the bus. It is possible that a VTRW alert would have been issued prior to the brake release had the brake not been engaged (VTRW alerts are suppressed by the brake pedal).

5.2 Safety Impact

Key findings from the analyses of driver response to alerts and driver attention are summarized in Table 5-2 and described in subsections5.2.1 and 5.2.2.

Table 5-2. Safety Impact Conclusion Summary

Safety Application/ Research Area	Conclusions
FCW	Trend toward faster driver reaction time when alerts were issued
CSW	Higher rate of driver response rate to alerts during the Redeployment, suggesting that the changes in the TRP DVI impacted driver behavior Drivers braked harder in response to CSW alerts between the baseline and Model Deployment, and between the Model Deployment and Redeployment
EEBL	No significant differences observed
PCW	Drivers braked in response to 4 of 37 valid PCW Alerts
VTRW	No changes in driver behavior observed in response to VTRW alerts
Driver Attention	Drivers rarely engaged in secondary tasks, and generally only did so when the bus was stopped. No negative behavior adaptations observed as a result of driving with the TRP

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5.2.1 Response to Alerts

Key results from the analysis of driver response to alerts are broken down by safety application.

5.2.1.1 FCW

- The IE observed a slight decrease in response time to FCW alerts for decelerating remote vehicles between both the Baseline and the Model Deployment test period, and the Baseline and Redeployment test periods, but the decrease was not significant in either case.
- The IE did not observe any changes in TTC at host vehicle brake onset, peak deceleration, mean deceleration, or minimum TTC between test periods.

5.2.1.2 CSW

- Drivers braked within 5 seconds of a CSW alert in less than 10 percent of alerts issued during the Baseline and Model Deployment test periods, but braked within 5 seconds of more than 60 percent of CSW alerts issued during the Redeployment. No changes were made to the application software between test periods, suggesting that this change in driver behavior was caused by the changes made to the driver interface.
- The IE did not observe any differences in response time to CSW alerts between test periods.
- There was a statistically significant increase in both peak and mean deceleration within 5 seconds of a CSW alert from the Baseline to the Model Deployment, from the Model Deployment to the Redeployment, and from the Baseline to the Model Deployment and Redeployment periods combined. The increase in peak deceleration between the Model Deployment and Redeployment test periods is likely due to the increased response rate, as a braking maneuver will create higher deceleration levels compared to when there is no braking maneuver.

- There was a statistically significant increase from the Baseline to the Model Deployment test period in both peak and mean lateral acceleration within 5 seconds of a CSW alert. This increase is likely due to the lower average speed at alert time during the Baseline period (the speed threshold for alerts to be issued was increased towards the end of the Baseline period).
- There was a statistically significant decrease in both peak and mean lateral acceleration from the Model Deployment to the Redeployment within 5 seconds of a CSW alert, indicating that drivers traversed the CSW-equipped curve less aggressively during the Redeployment.

5.2.1.3 EEBL

- The IE did not observe changes in mean or peak deceleration within 5 seconds of EEBL between the Baseline and the Model Deployment and Redeployment test periods combined.

5.2.1.4 PCW

- Drivers braked in response to four of 37 true PCW events. Fourteen of the 37 true PCW alerts were issued when the bus was stopped at the intersection (no response required), 6 were issued when the driver was already braking or braking for reasons other than the pedestrian presence, and drivers did not respond to 11 of the events because the pedestrian had already cleared, or was clearing the intersection.
- The IE did not observe any differences in driver response to PCW alerts between the Model Deployment and Redeployment test periods.

5.2.1.5 VTRW

- Drivers did not show a visible response to any of the 11 true VTRW alerts observed during the Model Deployment and Redeployment test periods.

5.2.2 Driver Attention

- The IE observed very few instances of the TRP drivers performing secondary tasks.
- Drivers were much more likely to perform secondary tasks during a PCW or VTRW, which is probably because these alert types can be issued when the bus is stationary.
- The IE did not observe any instances of unintended consequences or negative behavior adaptations when TRP drivers were driving with the TRP safety applications.

5.3 Driver Acceptance

This subsection summarizes key findings from both the survey and focus during the Model Deployment and the Redeployment test periods. Findings are organized in subsections for each of the five driver acceptance areas outlined in Section 4.1.1.

In interpreting the results of these analyses, it is important to stress that the sample sizes are very small and may be strongly influenced by individual idiosyncrasies of each driver and their driving experiences. This means there is a chance these results do not represent the majority of bus drivers nationwide. Also, as noted by the drivers in the focus groups, the usefulness of the system depends on the size of the city and the density and aggression of other vehicles and pedestrians on the road. Consequently, these results are not likely to be representative of the different environments and driving conditions nationwide.

Driver Acceptance results are summarized in Table 5-3 and described in subsections 5.3.1 through 5.3.5. .

Table 5-3. Safety Impact Conclusion Summary

Driver Acceptance Area	Conclusions
Usability	Easy to use (CSW rated the highest, FCW the lowest) Alerts easy to see and read (particularly during Redeployment) Despite incorrect alerts, applications rated understandable and alerts distinguishable
Perceived Safety Benefits	Safety benefits rated low (already good, careful drivers, already aware of situation). Better for inexperienced drivers in big cities with more traffic? Low trust in alerts (due to incorrect alerts). Perception of safety increase did go up with Redeployment (experimental effect since they knew they were testing improvements?)
Unintended Consequences	Risk for unintended consequences mostly neutral: some complaints of distraction, inadequate for overreliance
Desirability	Little desire for system overall CSW desired most for accuracy/usefulness FCW desired least for false alerts and distraction PCW liked for accuracy but still regarded neutrally for desirability Very little feedback for the VTRW and EEBL and largely neutral
Privacy	Concern for privacy mixed, largely neutral (expectations of privacy different for bus drivers—they're on the job, not driving personal vehicle) One driver concerned that system hacking could leak driving info to insurance companies who would raise their rates Passenger opinion matters for drivers and could affect job security; one participant embarrassed by alerts visible to passengers

Volpe

5.3.1 Usability

Participants generally found the TRP system easy to use, giving the CSW the highest rating and the FCW the lowest. The alerts were considered easy to see and read (particularly after improvements were made for the Redeployment). Despite receiving incorrect alerts, the applications were thought to be understandable and their alerts distinguishable from each other (although cautions were more difficult to distinguish from warnings for a given application).

- All experienced participants (the Top-7) thought the display was easily seen.
- All Top-7 participants thought that alerts caught their attention when they first appeared (opinions were more mixed with less experienced participants included).
- Six out of 7 Top-7 participants thought the alerts were easy to read and understand.

- Six out of 7 Top-7 participants thought it easy to distinguish between the alerts of the different applications. Distinguishing between cautions and warnings for a given application was more difficult.
- The percentage of all participants who agreed that it was easy to distinguish the alerts from the different applications increased significantly between the Model Deployment and the Redeployment, going from 31 to 50 percent. Participants who disagreed decreased from 16 to 0 percent.
- Some participants remarked that training was useful in learning to use the system, but opinions among the Top-7 participants were fairly unanimous that no additional training was needed for any of the applications.
- The Redeployment resulted in a more easily monitored tablet (19 out of 24 participants).
- The verbal alerts used in the Redeployment were preferred over the tones (15 out of 23 participants).
- The extended display time in the Redeployment enabled the alert being issued to be more easily identified (20 out of 23 participants).

5.3.2 Perceived Safety Benefits

Participants did not view the safety applications as providing many safety benefits, mainly because participants viewed themselves as good and careful drivers, already aware of potential collision scenarios before the system alerted them. They suggested inexperienced drivers in bigger cities where traffic tends to be more complex and aggressive might find the system useful. Participants also had little trust in most alerts, due to the number of incorrect alerts they felt they received. Nonetheless, the perception of the safety increase from using the system did increase for the Redeployment test period, although this may have been an experimental effect since participants knew they were testing modifications designed to improve the system (there was no control or counterbalance for this effect).

- The majority of experienced participants (4 out of 7 Top-7 participants) thought the system overall did not increase their driving safety (only 1 did).
- The percentage of participants who thought the system overall increased their driving safety increased from 16 to 39 percent between the Model Deployment and the Redeployment test periods (counting participants of all experience levels greater than zero). This increase was statistically significant.

5.3.3 Unintended Consequences

The risk for unintended consequences was mostly neutral, with some participants reporting concern that the displays could distract one from the road. Generally the system was seen as inadequate to over-rely on. Only a minority of participants (2 out of 3 Top-7 participants) noticed changes in their driving behavior, though these changes did not include overreliance in either case.

- Five out of 7 Top-7 participants were neutral about the alerts being distracting, with 1 agreeing and 1 disagreeing about whether they were. The ratios were similar for participants with less experience with the system.
- Two out of 3 Top-7 participants reported noticing changes in their driving behavior, including increased awareness for situations that could cause alerts, driving to avoid those situations, and driving more cautiously after receiving an alert.

5.3.4 Desirability

The surveys showed very little desire for the system and the focus groups essentially showed none at all. Among the individual applications, the CSW was most desired for its accuracy and usefulness. The FCW was least desired, especially due to false alerts and distraction (the ease of use and understanding of the FCW were not negatively reviewed). The PCW was liked for its understandability but was still regarded neutrally for desirability. There was very little feedback for the VTRW and EEBL and it was largely neutral.

- Overall satisfaction was mostly neutral (4 of the Top-7 participants, 22 out of 32 total).
- The CSW was the most desired application (3 out of 3 of the Top-7 participants) and the FCW was the least desired (1 out of 6 Top-7 participants). Opinions were mixed for the PCW, VTRW, and EEBL.

5.3.5 Privacy

Concern for privacy was mixed and largely neutral. Expectations of privacy are also different for bus drivers since they are on the job and not driving their personal vehicle. Nonetheless, one participant was concerned that the system might be hacked and their driving information become available to insurance companies that would raise their rates.

Another factor unique for bus drivers (not present for people driving their personal vehicles or for commercial truck drivers) is the presence of passengers and the importance of their perceptions of the system to the driver. One participant was embarrassed by alerts visible to passengers that might give the impression that the participant was a bad driver (complaints could impact a driver’s job security).

- Overall, given that bus drivers are on the job while using this technology, it is not surprising that they would have less concern for being monitored than people using their personal vehicles in their private lives.Three out of 7 Top-7 participants were neutral over concerns about the potential to monitor their driving behavior, and 2 out of 7 were concerned. The ratios were similar for all participants combined.

References

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[7] S. Stevens, "Do drivers brake in response to rear-end colision events or alerts from forward collision warning systems?," National Highway Traffic Safety Administration, Washington, DC, 2011.

Appendix A. List of Acronyms

ASD	Aftermarket Safety Device
BSM	Basic Safety Message
CAN	Controller Area Network
CSW	Curve Speed Warning
DAS	Data Acquisition System
DSRC	Designated Short-Range Communication
DVI	Driver-Vehicle Interface
EEBL	Emergency Electronic Brake Lights
FCW	Forward Collision Warning
IE	Independent Evaluator
IQR	Interquartile Range
ITS	Intelligent Transportation Systems
IV	Integrated Vehicle
LVD	Lead Vehicle Decelerating
LVM	Lead Vehicle Moving
LVS	Lead Vehicle Stopped
m	mile
m/s	miles per second
mph	miles per hour
PCW	Pedestrian Crash Warning
RSD	Retrofit Safety Device
RSE	Roadside Safety Equipment
RV	Remote Vehicle
s	Second
SPAT	Signal Phase and Timing
TRP	Transit Retrofit Package
TTC	Time-to-Collision
U.S. DOT	United States Department of Transportation
UMTRI	University of Michigan Transportation Research Institute
Volpe	John A.Volpe National Transportation Systems Center
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VAD	Vehicle Awareness Device
VTRW	Vehicle Turning Right Warning

Appendix B. Objective Data Elements

Category	Attribute	Source	Storage Location	Data Frequency
Primary Keys	Device ID (Fixed BSM bytes)	WSU Config File	DAS	10 Hz
Primary Keys	Time	DAS	DAS	10 Hz
Primary Keys	Trip	DAS	DAS	10 Hz
Forward Ranging Sensor	Azimuth	MobilEye	DAS	10 Hz
Forward Ranging Sensor	In-path target	MobilEye	DAS	10 Hz
Forward Ranging Sensor	Range	MobilEye	DAS	10 Hz
Forward Ranging Sensor	Lateral distance to target	MobilEye	DAS	10 Hz
Forward Ranging Sensor	RangeRate	MobilEye	DAS	10 Hz
Forward Ranging Sensor	Target ID	MobilEye	DAS	10 Hz
Forward Ranging Sensor	Target status	MobilEye	DAS	10 Hz
Forward Ranging Sensor	Target type (moving/stopped)	MobilEye	DAS	10 Hz
Forward Ranging Sensor	Target Type (object)	MobilEye	DAS	10 Hz
GPS/Mapping	Availability	GPS	DAS	10 Hz
GPS/Mapping	Elevation	GPS	DAS	10 Hz
GPS/Mapping	GPS Heading	GPS	DAS	10 Hz
GPS/Mapping	GPS Position Accuracy	GPS	DAS	10 Hz
GPS/Mapping	GPS Speed	GPS	DAS	10 Hz
GPS/Mapping	GPS Time	GPS	DAS	10 Hz
GPS/Mapping	Latitude	GPS	DAS	10 Hz
GPS/Mapping	Longitude	GPS	DAS	10 Hz
GPS/Mapping	Number of Satellites	GPS	DAS	10 Hz
In Vehicle	Brake pedal activation	J1939	DAS	10 Hz
In Vehicle	Cruise control status	J1939	DAS	10 Hz
In Vehicle	Lateral acceleration	IMU	DAS	10 Hz
In Vehicle	Longitudinal acceleration	IMU	DAS	10 Hz
In Vehicle	Speed	J1939	DAS	10 Hz

Category	Attribute	Source	Storage Location	Data Frequency
In Vehicle	Steering wheel position	N/A		10 Hz
In Vehicle	Throttle position	J1939	DAS	10 Hz
In Vehicle	Transmission State	J1939	DAS	10 Hz
In Vehicle	Yaw Accel	IMU	DAS	10 Hz
In Vehicle	Yaw rate	IMU	DAS	10 Hz
Lane Tracking Sensor	Availability	*MobilEye*	*DAS*	*10 Hz*
Lane Tracking Sensor	Boundary type	MobilEye	DAS	10 Hz
Lane Tracking Sensor	Confidence	Mobileye	DAS	10 Hz
Lane Tracking Sensor	Lane change flag	MobilEye	DAS	10 Hz
Lane Tracking Sensor	Lane width	MobilEye	DAS	10 Hz
Lane Tracking Sensor	Vehicle position within lane	MobilEye	DAS	10 Hz
V2I	PCW SPAT	RSE		10 Hz
V2V (OBE data)	BSM log	WSU Transmitted	DAS	10 Hz
V2V (OBE data)	Confidence (threat)	WSU	DAS	10 Hz
V2V (OBE data)	Device type communicating with	WSU	DAS	10 Hz
V2V (OBE data)	DVI information	WSU	DAS	10 Hz
V2V (OBE data)	Enabled (Baseline/Treatment)	TBD		10 Hz
V2V (OBE data)	Alert Type	WSU	DAS	10 Hz
V2V (OBE data)	Application	WSU	DAS	10 Hz
V2V (OBE data)	Threat level	WSU	DAS	10 Hz
V2V (OBE data)	Threat Priority	WSU	DAS	10 Hz
V2V (OBE data)	Threat ID	WSU	DAS	10 Hz
Vehicle Target(s)	RV Azimuth	WSU	DAS	10 Hz
Vehicle Target(s)	RV Brake Status	WSU	DAS	10 Hz
Vehicle Target(s)	RV Elevation	WSU	DAS	10 Hz

Category	Attribute	Source	Storage Location	Data Frequency
Vehicle Target(s)	RV Heading	WSU	DAS	10 Hz
Vehicle Target(s)	RV Latitude	WSU	DAS	10 Hz
Vehicle Target(s)	RV Location	WSU	DAS	10 Hz
Vehicle Target(s)	RV Longitudinal Acceleration	WSU	DAS	10 Hz
Vehicle Target(s)	RV Longitude	WSU	DAS	10 Hz
Vehicle Target(s)	RV Range Rates	WSU	DAS	10 Hz
Vehicle Target(s)	RV Speeds	WSU	DAS	10 Hz
Vehicle Target(s)	RV Target ID	WSU	DAS	10 Hz
Cameras (all videos continuous)	Face (infrared)	Camera	DAS	10 Hz
Cameras (all videos continuous)	Left Front	Camera	DAS	10 Hz
Cameras (all videos continuous)	Right Front	Camera	DAS	10 Hz
Cameras (all videos continuous)	Left Side	Camera	DAS	10 Hz
Application Data	Alert Type	WSU	Tablet Storage/DAS	Event-based
Application Data	Alert Start Time	WSU	Tablet Storage/DAS	Event-based
Application Data	Alert End time	WSU	Tablet Storage/DAS	Event-based
Application Data	RV Device ID	WSU	Tablet Storage/DAS	Event-based

Appendix C. Coded Variables and Definitions

General Coding (all alert types)

Driver Behavior

Eyes-Off-Driving Task (due to secondary tasks)

Did the driver take their eyes off the driving task for over 1.5 seconds within the 5 seconds before the alert was issued?

Secondary Tasks Related to EODT

Activity driver was engaged in when eyes were off driving task:

0. None – Select None if "eyes off driving task" was coded "No"
1. Grooming – Driver is applying makeup, using rearview mirror to look at himself, scratching, etc.
2. Eating – Driver is unwrapping food, eating snacks, or drinking a beverage.
3. Talking to/looking at passengers – Engaged in conversation with other occupants or looking at/distracted by other occupants.
4. Dialing phone – Driver is dialing his phone. This can be differentiated from texting or data input if the driver is seen engaging in a phone conversation directly afterwards.
5. Text messaging – Driver is texting or engaging in any data entry on his phone.
6. Talking/listening to phone – Driver is engaged in a call on his cell phone.
7. Reading cell phone – Looking at phone but not dialing or talking.
8. Talking/listening to Bluetooth headset – Driver is engaged in a call via a Bluetooth headset or other hand-free device.
9. Searching interior – Driver is looking around interior of the vehicle, either front or back seat.
10. Reaching for object in vehicle – Driver is retrieving object from somewhere in vehicle.
11. Adjusting controls – Driver reaching towards center console to adjust in-vehicle controls.
12. Adjusting/using aftermarket device – Driver is using device such as navigation system or radar detector.
13. Reading – Reading material in view, eyes focused toward reading material.
14. Singing/whistling
15. Looking to the side/outside car – Driver is focused on something outside the car that does not appear to be related to the driving task.
16. Yawning
17. Eyes closed >1 second – Driver's eyes are visibly closed for a period of time longer than one second (10 data records).
18. Smoking/lighting cigarette – Cigarette is visible, driver is engaging in any smoking related behaviors including opening window, ashing, smoking, opening cigarette box, etc.

19. Other – Any visible distraction that does not fit previous categories.
20. Unknown – Secondary task cannot be determined.

Secondary Tasks 1, 2, and 3

Other secondary tasks driver was performing within 10 seconds of alert:

TRP Bus

TRP Bus Maneuver

Maneuvers made by TRP bus before, or at alert time

0. Going straight - Driver remains in only one lane, without making any maneuvers.
1. Changing lanes - Driver executes a lane change to either the left or right on a multi-lane road just before the alert, is making a lane change at the time of the alert, or is showing intent to make a lane change (checking blind spot/mirrors). Blinker may or may not be used.
2. Turning – Driver is turning either left or right or bearing off from one road to another.
3. Merging – Driver is merging into moving traffic on another road, or merging when a lane ends on their current road.
4. Passing opposite direction – Driver is passing a slower lead vehicle on a 2 lane, opposite direction road (passing in lane of oncoming traffic).
5. Stopped
6. Other

TRP Bus Position

Position of TRP bus around the time of the alert:

0. Straight road – Vehicle is traveling on straight road without any intersecting roads.
1. In curve – Vehicle is navigating a curve.
2. Curve entry – Vehicle is approaching or just entering a curve.
3. Curve exit – Vehicle is exiting a curve or has just completed the negotiation of a curve.
4. Approaching intersection – Vehicle is approaching an intersection (or traffic queue at intersection) or entrance to a road (ex. end of driveway or exiting a shopping plaza). For FCW alerts, code any FCW related to an intersection (ex. approaching a vehicle slowing to stop at a traffic light) as approaching intersection.
5. Stopped at intersection – Vehicle is stopped at intersection (or in traffic queue at intersection), or entrance to a road (ex. end of driveway or exiting a shopping plaza) waiting to make maneuver into intersection.
6. In intersection – Vehicle is passing through, or stopped in the intersection.

Steering Response (FCW)

Time of driver steering response to threat

TRP Bus Lane Position at Alert Time (FCW)

Vehicle's location within the lane at the moment the alert was issued:

0. In Lane – Vehicle is maintaining travel in the same lane, or is initiating a lane change but has not yet crossed the lane line.
1. Between lanes – Vehicle is in the process of making a lane change maneuver, or has drifted out of their lane.
2. In adjacent lane – Vehicle has just completed a lane change maneuver and is completely in the adjacent lane.

Environmental

Light

Day/night

Weather Clear/Rain/Snow

FCW/EEBL

Pre-Crash Scenario

The pre-crash scenario describes the geometry and dynamics of the vehicles involved in the alert:

0. Lead vehicle stopped – Rear end crash scenario where the remote vehicle is stopped. Select this code only if the vehicle is never seen moving in the video (FCW application).
1. Lead vehicle decelerating – Rear end crash scenario where the remote vehicle is decelerating (generally braking) or stopping (FCW and EEBL applications).
2. Lead vehicle constant speed – Rear end crash scenario where the remote vehicle is maintaining constant speed and the TRP bus is traveling faster than the target. Also code constant speed if RV is accelerating (FCW and EEBL applications).

Lead Vehicle Target

Forward Target location

Location of target vehicle at alert time:

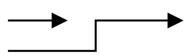
0. No forward target – No remote vehicle could be detected.
1. In lane – Remote vehicle was in the same lane as the TRP bus at the time the alert was issued. Remote vehicle is considered to be in-lane if any part of the vehicle is in the TRP bus lane at the alert time. Make note in comment if there are one or more unequipped RVs BETWEEN the TRP bus and the equipped RV at the alert time (i.e. the RV is not the last vehicle in the traffic queue).
2. One lane over – Remote vehicle was in the lane adjacent to the TRP bus (if vehicle between adjacent lane and 2 lanes over, code 1 lane over).
3. Two or more lanes over – Remote vehicle was 2 or more lanes over from the TRP bus.
4. Left turn lane- Remote vehicle is waiting at an intersection in the left turn lane.
5. Behind – Remote vehicle is either adjacent to, or behind the TRP bus.
6. Vehicles separating, In path – Remote vehicle is in the same lane as the TRP bus, but the gap between the vehicles is separating.

7. Vehicles separating, out-of-path – Remote vehicle is in the adjacent lane and the gap between the vehicles is separating.
8. Unsure – Code all other forward target scenarios as unsure. For example, if RV in an adjacent parking lot (as shown below). Describe details in comment field.

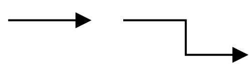
Forward Target Maneuver

Maneuvers of forward target within one second before or after the alert time:

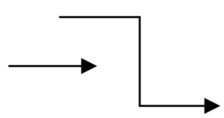
0. No forward target
1. Going straight - Lead vehicle is traveling in its current lane without making any maneuvers. If remote vehicle is stopped code as going straight.
2. Cut in - Lead vehicle executes a lane change from an adjacent lane into the lane of travel of the TRP bus, or lead vehicle turns onto roadway in front of TRP bus (within approximately 5 seconds before the alert). Lead vehicle may cut in from the other direction (as shown below):



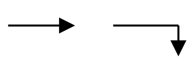
3. Cut out - Lead vehicle executes a lane change to adjacent lane so that they are no longer in the same lane of travel of the TRP bus (within approximately 5 seconds before the alert). Lead vehicle may cut out to the other direction (as shown below):



4. Cut in and out - Lead vehicle executes a cut out immediately after a cut in; i.e., moves from one adjacent lane to the adjacent lane on the other side of the vehicle. Lead vehicle may execute this to the other direction (as shown below):



5. Turning off - Lead vehicle is preparing to turn onto another road (is slowing), or is turning onto another road. Use blinker to help determine if the lead vehicle intends to turn. Lead vehicle may turn into the other direction (as shown below):



6. Other – Remote vehicle is making a maneuver other than listed above (describe in comment field).
7. Unsure

Forward Target Road Position

Characteristics of the road where the lead vehicle is at the time of the alert:

0. No forward target
1. Straight road

2. In curve – Lead vehicle is navigating curve.
3. Curve entry – Lead vehicle is entering, or about to enter a curve.
4. Curve exit – Lead vehicle is completing the negotiating of a curve.
5. Unsure

Lead Vehicle Brake Onset Time

Time when the remote vehicle's brake lights first appeared in the video.

Lead Vehicle Turn Signal

Lead vehicle use of turn signal during alert scenario.

CSW

TRP Bus Position

Bus position relative to curve at alert time:

0. In Curve – Bus is navigating a curve.
1. Curve Entry – Bus is approaching or just entering a curve.
2. Curve Exit – Bus is exiting a curve or has just completed the negotiation of a curve.

PCW

Bus Position at Alert Onset

Position/maneuver of the bus at the time of the alert:

0. Stopped-1st in queue – Bus is stopped and waiting first at the light at time of alert or warning.
1. Stopped-2nd or more in queue – Bus is stopped and waiting second or further back in the queue at the light at time of alert or warning.
2. Approaching Intersection – Going, green (or right on red) (first in queue) – Bus is approaching the intersection, there are no vehicles in front of it in its lane, and it has a green light (or can turn right on red), so it is not slowing to a stop.
3. Approaching Intersection – Stopping, red (first in queue) – Bus is approaching the intersection, there are no vehicles in front of it in its lane, and it has a red light (and can't turn right on red), so it is slowing to a stop.
4. Turning (In Intersection) – Bus is the intersection area (where the two roads overlap), and is turning between the two roads.
5. In/Past Crosswalk – Cabin of the bus is within the area or the target crosswalk or beyond it. (This may result in the middle or rear of the bus still traversing the crosswalk while the front of the bus is past it, but by this time an alert or warning will not do the driver any good.)
6. Approaching back of queue of stopped traffic – Bus is approaching the rear of a multi-car queue of stopped traffic.

Bus Route

Did bus traverse intended crosswalk:

0. Across Crosswalk – Bus drove across the equipped crosswalk (took a right on Fuller Street or a left on E. Medical Center Drive)
1. Not Across Crosswalk – Bus did not drive over the equipped crosswalk.
2. Unsure

Pedestrian Position at Time of Alert

0. On Sidewalk – Pedestrian in on sidewalk (either before or after crossing)
1. Leaving Sidewalk – Pedestrian is departing sidewalk or just entering the crosswalk
2. Crossing – Pedestrian is completely in the crosswalk and committing to cross
3. On island – Pedestrian is approaching, arriving, or waiting on the island
4. Out-of-path – Pedestrian is near, or in the crosswalk that is perpendicular to the bus approach (the first crosswalk they cross)
5. None – No pedestrian in the crosswalk or on the sidewalk preparing to cross the crosswalk
6. Vehicle in crosswalk – Vehicle in the cross walk that was mistaken for a pedestrian
7. Unsure – Unable to detect pedestrians

VTRW

Driver Intent to Proceed

Did the driver of the bus show intent to move forward into traffic during alert scenario (e.g., checking mirrors, brake release, etc.)

Target Approach Position

0. Behind Bus – RV is initially in the same lane and behind the TRP bus, it then pulls out and attempts to drive around the TRP bus.
1. Adjacent Lane – RV starts in the lane adjacent to the TRP bus, pulls alongside TRP bus (while it is stopped) and then cuts in front of the TRP bus
2. Two or more Lanes Over – RV is 2 or more lanes away from TRP bus and is always far away from the TRP bus.
3. Unsure

Target Lateral Position at Time of Alert

0. Behind Bus
1. Adjacent
2. Two Lanes Over
3. In Front – In-Path
4. In Front – Adjacent Lane
5. Unsure

Target Maneuver

0. Turning Right – RV is turning right just beyond where the TRP bus is stopped
1. Cut-In – RV is entering the TRP bus's lane and intends to stay there.
2. Going Straight – RV doesn't go in front of the TRP bus (either to turn right or just cut in) but continues in its lane
3. Other
4. Unsure

Target Lane Change Time

Time stamp of when the centerline of RV crosses the lane line into the adjacent lane to the bus.

Unequipped Vehicle in Front of TRP bus

Yes (0) or No (1) – is there an unequipped vehicle parked or stopped in front of the TRP bus that acts as a buffer from the RV as it goes around these two or more vehicles?

Appendix D. Post-Drive Surveys

Post-drive survey for the Model Deployment compiled by UMTRI.

Participant # __________

Date __________

Bus Operator Survey of Transit Safety Retrofit Package (TRP)

The Transit Safety Retrofit Package is intended to improve the safety of transit bus travel through the use of five applications of Connected Vehicle technology (see below). This survey asks for your opinions on the usability, perceived safety benefits, understandability, desirability, and any security/privacy concerns with each of the individual applications and with TRP as a whole. The seven sections of the questionnaire are as follows:

- Section I – Overall Impressions of TRP
- Section II – Forward Collision Warning (FCW)
- Section III – Pedestrian in Crosswalk Warning (PCW)
- Section IV – Vehicle Turning Right Warning (VTRW)
- Section V – Emergency Electronic Brake Lights (EEBL)
- Section VI – Curve Speed Warning (CSW)
- Section VII – Driver Information

Sections II through VI ask nearly identical questions about each of the applications. For those applications that you did not experience a caution or warning, only the first question of the section needs to be completed.

Please complete the survey as soon as possible.

Thank you.

Bus Operator Survey of the Transit Safety Retrofit Package (TRP)

Section I – Overall Impressions

1. What did you like *most* about the Transit Safety Retrofit Package?

2. What did you like *least* about the Transit Safety Retrofit Package?

3. Please describe any difficulties you encountered with the Transit Safety Retrofit Package?

   3a. Were the issues resolved?
   - ❑ N/A
   - ❑ No
   - ❑ Yes

4. Was the display easily seen from your driver's seat?
   - ❑ No
   - ❑ Yes

5. Were the auditory notifications easily heard?
   - ❑ No
   - ❑ Yes

6. Did any passengers comment on the TRP cautions and warnings? If so, what were their comments?
   - ❑ No
   - ❑ Yes Comments: ______

Thinking about the Transit Safety Retrofit Package as a whole, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
7. The cautions and warnings caught my attention when they first appeared.	1	2	3	4	5	6	7
Comments:							
8. The cautions and warnings were easy to read and understand.	1	2	3	4	5	6	7
Comments:							
9. The cautions and warnings were distracting.	1	2	3	4	5	6	7
Comments:							
10. Monitoring or interpreting the TRP cautions and warnings was no more distracting than using other driver equipment.	1	2	3	4	5	6	7
Comments:							
11. It was easy to tell the difference between cautions and warnings for the different applications (i.e., not confusing one application with another).	1	2	3	4	5	6	7
Comments:							
12. I am concerned about the potential of the Transit Retrofit Package enabling my driving patterns to be monitored.	1	2	3	4	5	6	7
Comments:							

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
13. Overall, I was satisfied with the Transit Safety Retrofit Package.	1	2	3	4	5	6	7
Comments:							
14. Overall, I think the Transit Safety Retrofit Package increased my driving safety.	1	2	3	4	5	6	7
Comments:							

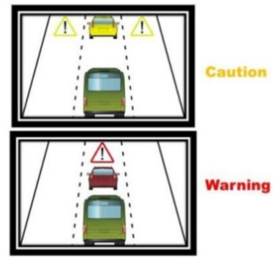
15. Did you notice any changes in your driving behavior as a result of driving with the Transit Safety Retrofit Package?
    - ❑ No *(skip to question 17)*
    - ❑ Yes

16. What behaviors do you think changed as a result of having the TRP technology in your bus? *(check all that apply)*
    - ❑ I became more aware of driving situations that could cause a caution or warning.
    - ❑ I was more cautious after receiving a caution or warning.
    - ❑ I started to pay less attention because I relied on the cautions and warnings.
    - ❑ I drove differently to prevent the system from warning me.
    - ❑ Other ____________________

17. Were any near misses avoided because of the presence of TRP? If so, please describe.
    - ❑ No
    - ❑ Yes   Comments: ____________________

18. How does the Transit Safety Retrofit Package impact the ability to do your job (positively and/or negatively)?

<u>Section II – Forward Collision Warning (FCW)</u>



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.

19. Did you ever receive an FCW caution or warning?
    - ❑ No *(skip to Section III)*
    - ❑ Yes

20. What did you like *most* about the FCW application?

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21. What did you like *least* about the FCW application?

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Thinking about the FCW application, please indicate the extent to which you agree or disagree with each statement. *(Circle <u>one</u> response for <u>each</u> question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
22. The difference between an FCW caution and warning was clearly evident on the display.	1	2	3	4	5	6	7
Comments:							
23. It was clear *why* the FCW issued a caution or warning when it did (i.e., there was another vehicle ahead that was stopped or moving more slowly than the bus).	1	2	3	4	5	6	7
Comments:							
24. I trusted the FCW cautions and warnings.	1	2	3	4	5	6	7
Comments:							

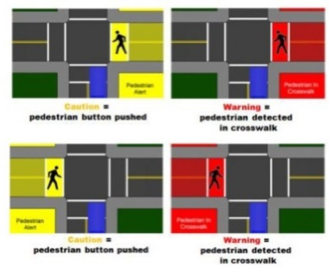
STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
25. The FCW was effective at drawing attention to the presence of a vehicle ahead that was stopped or was moving slowly.	1	2	3	4	5	6	7
Comments:							
26. The FCW was easy to use and understand.	1	2	3	4	5	6	7
Comments:							
27. Additional training was needed in order to utilize FCW properly.	1	2	3	4	5	6	7
Comments:							
28. I would like FCW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

29. How often did you receive FCW cautions or warnings that you felt were incorrect (i.e., there was no danger present)?
- ❑ Multiple times per shift
- ❑ Once per shift
- ❑ Every few shifts
- ❑ Very rarely
- ❑ Never

30. Please describe anything that you would change about the FCW application?

Section III– Pedestrian in Crosswalk Warning (PCW)

PCW helps to warn drivers of a pedestrian that has pushed the crosswalk signal and is near or in the second crosswalk that the bus will pass through as it turns at an intersection.



31. Did you ever receive a PCW caution or warning?
    - ❑ No *(skip to Section IV)*
    - ❑ Yes

32. What did you like *most* about the PCW application?

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33. What did you like *least* about the PCW application?

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Thinking about the PCW application, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

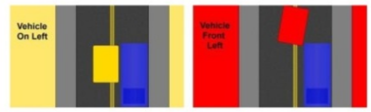
STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
34. The difference between a PCW caution and warning was clearly evident on the display.	1	2	3	4	5	6	7
Comments:							
35. It was clear *why* the PCW issued a caution when it did (i.e., there was a pedestrian waiting to cross).	1	2	3	4	5	6	7
Comments:							
36. It was clear *why* the PCW issued a warning when it did (i.e., there was a pedestrian in the crosswalk).	1	2	3	4	5	6	7
Comments:							

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
37. I trusted the PCW cautions and warnings.	1	2	3	4	5	6	7
Comments:							
38. The PCW was effective at drawing attention to the presence of a pedestrian in or near the crosswalk.	1	2	3	4	5	6	7
Comments:							
39. The PCW was easy to use and understand.	1	2	3	4	5	6	7
Comments:							
40. Additional training was needed in order to utilize PCW properly.	1	2	3	4	5	6	7
Comments:							
41. I would like PCW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

42. How often did you receive PCW cautions or warnings that you felt were incorrect (i.e., there was no danger present)?
- ❑ Multiple times per shift
- ❑ Once per shift
- ❑ Every few shifts
- ❑ Very rarely
- ❑ Never

43. Please describe anything that you would change about the PCW application?

<u>Section IV – Vehicle Turning Right Warning (VTRW)</u>



VTRW helps to warn drivers of a vehicle pulling up next to the bus from the rear that potentially may turn in front of the bus while at a bus stop.

44. Did you ever receive a VTRW caution or warning?
    - ❑ No *(skip to Section V)*
    - ❑ Yes

45. What did you like *most* about the VTRW application?

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46. What did you like *least* about the VTRW application?

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Thinking about the VTRW application, please indicate the extent to which you agree or disagree with each statement. *(Circle <u>one</u> response for <u>each</u> question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
47. The difference between a VTRW caution and warning was clearly evident on the display.	1	2	3	4	5	6	7
Comments:							
48. It was clear *why* the VTRW issued a caution when it did (i.e., there was another vehicle pulling up next to the bus on the left side from behind).	1	2	3	4	5	6	7
Comments:							
49. It was clear *why* the VTRW issued a warning when it did (i.e., there was another vehicle turning right in front of the bus).	1	2	3	4	5	6	7
Comments:							

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
50. I trusted the VTRW cautions and warnings.	1	2	3	4	5	6	7
Comments:							
51. The VTRW was effective at drawing attention to the presence of a vehicle pulling up on the left side.	1	2	3	4	5	6	7
Comments:							
52. The VTRW was easy to use and understand.	1	2	3	4	5	6	7
Comments:							
53. Additional training was needed in order to utilize VTRW properly.	1	2	3	4	5	6	7
Comments:							
54. I would like VTRW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

55. How often did you receive VTRW cautions or warnings that you felt were incorrect (i.e., there was no danger present)?
- ❑ Multiple times per shift
- ❑ Once per shift
- ❑ Every few shifts
- ❑ Very rarely
- ❑ Never

56. Please describe anything that you would change about the VTRW application?

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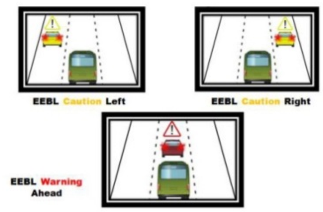
Section V – Emergency Electronic Brake Lights (EEBL)



EEBL tells you if there is a stopped vehicle or one slowing down quickly, either directly in front of you or some distance ahead.

57. Did you ever receive an EEBL caution or warning?
    - ❑ No *(skip to Section VI)*
    - ❑ Yes

58. What did you like *most* about the EEBL application?

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59. What did you like *least* about the EEBL application?

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Thinking about the EEBL application, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
60. The difference between an EEBL caution and warning was clearly evident on the display.	1	2	3	4	5	6	7
Comments:							
61. It was clear *why* the EEBL issued a caution or warning when it did (i.e., there was another vehicle ahead that was braking hard).	1	2	3	4	5	6	7
Comments:							
62. I trusted the EEBL cautions and warnings.	1	2	3	4	5	6	7
Comments:							

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
63. The EEBL was effective at drawing attention to the presence of a vehicle ahead that was braking hard.	1	2	3	4	5	6	7
Comments:							
64. The EEBL was easy to use and understand.	1	2	3	4	5	6	7
Comments:							
65. Additional training was needed in order to utilize EEBL properly.	1	2	3	4	5	6	7
Comments:							
66. I would like EEBL to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

67. How often did you receive EEBL cautions or warnings that you felt were incorrect (i.e., there was no danger present)?
   - ❑ Multiple times per shift
   - ❑ Once per shift
   - ❑ Every few shifts
   - ❑ Very rarely
   - ❑ Never

68. Please describe anything that you would change about the EEBL application?

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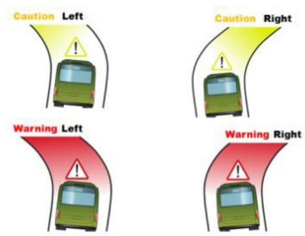
<u>Section VI – Curve Speed Warning (CSW)</u>

CSW helps to warn drivers that a curve is being taken at too high of a speed.



69. Did you ever receive a CSW caution or warning?
    - ❑ No *(skip to Section VII)*
    - ❑ Yes

70. What did you like *most* about the CSW application?

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71. What did you like *least* about the CSW application?

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Thinking about the CSW application, please indicate the extent to which you agree or disagree with each statement. *(Circle <u>one</u> response for <u>each</u> question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
72. The difference between a CSW caution and warning was clearly evident on the display.	1	2	3	4	5	6	7
Comments:							
73. It was clear *why* the CSW issued a caution or warning when it did (i.e., the bus was being driven potentially too fast through the curve).	1	2	3	4	5	6	7
Comments:							
74. I trusted the CSW cautions and warnings.	1	2	3	4	5	6	7
Comments:							

STATEMENT	Strongly Disagree	Disagree	Slightly Disagree	Neither Agree nor Disagree	Slightly Agree	Agree	Strongly Agree
75. The CSW was effective at drawing attention to the situation in which the curve was being taken at a high speed.	1	2	3	4	5	6	7
Comments:							
76. The CSW was easy to use and understand.	1	2	3	4	5	6	7
Comments:							
77. Additional training was needed in order to utilize CSW properly.	1	2	3	4	5	6	7
Comments:							
78. I would like CSW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

79. How often did you receive CSW cautions or warnings that you felt were incorrect (i.e., there was no danger present)?
- ❑ Multiple times per shift
- ❑ Once per shift
- ❑ Every few shifts
- ❑ Very rarely
- ❑ Never

80. Please describe anything that you would change about the CSW application?

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Section VII – Driver Information

81. What is your current operator category?
    - ❑ Fulltime
    - ❑ Student

82. How often did you drive a TRP-equipped bus?
    - ❑ Multiple times per week
    - ❑ Once per week
    - ❑ A couple times per month
    - ❑ Once per month
    - ❑ Less than once per month

83. Would you want similar Connected Vehicle applications on your personal vehicle?
    - ❑ No
    - ❑ Yes

Please offer any additional comments, suggestions, or other observations.

Thank you for your participation. Please return completed survey to Dillon Funkhouser.

The post-drive survey for the Redeployment:

Participant # __________

Date __________

Bus Operator Survey of Transit Safety Retrofit Package (TRP)

The Transit Safety Retrofit Package is intended to improve the safety of transit bus travel through the use of five applications of Connected Vehicle technology (see below). This survey asks for your opinions on each of the individual applications and with TRP as a whole.

You will be paid $25 for completing this survey and returning it to Dillon Funkhouser.

Thank you.

Bus Operator Survey of the Transit Safety Retrofit Package (TRP)

1. What did you like *most* about the Transit Safety Retrofit Package?

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2. What did you like *least* about the Transit Safety Retrofit Package?

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3. Please describe any difficulties you encountered with the Transit Safety Retrofit Package?

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4. Was the display easily monitored from your driver's seat?

- ❑ No
- ❑ Yes

5. Did the repositioning of the Tablet from the first round improve your ability to monitor the Tablet?

- ❑ No
- ❑ Yes

6. Did you prefer the Voice-based audio alerts used in Round 2 or did you prefer the Tone-based audio alerts used in Round 1?

- ❑ Preferred Voice-based Audio Alerts
- ❑ Preferred Tone-based Audio Alerts

7. Did you find it easier to identify what type of warning was being presented with the extended display time? (Display stayed on longer after a warning)

- ❑ No
- ❑ Yes

8. Was the extended time sufficient to determine what was being displayed or would you have preferred it remained on the display longer after a warning?

- ❑ Sufficient time to identify warning type
- ❑ Would like the display to remain on longer after a warning to help me identify the warning type

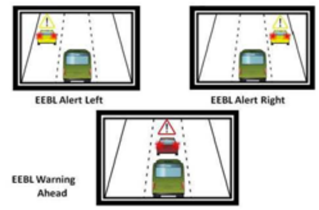
Thinking about the Transit Safety Retrofit Package as a whole, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
6. The alerts and warning were easy to immediately notice when they first appeared.	1	2	3	4	5	6	7
Comments:							
7. The alerts and warnings were easy to read.	1	2	3	4	5	6	7
Comments:							
8. It was easy to tell the difference between alerts and warnings from the different applications (i.e., not confusing one application with another).	1	2	3	4	5	6	7
Comments:							
9. Overall, I think the Transit Safety Retrofit Package increased my driving safety.	1	2	3	4	5	6	7
Comments:							

10. Were any near misses avoided because of the presence of TRP? If so, please describe.
- ❑ No
- ❑ Yes Comments: ______________________________

11. How does the Transit Safety Retrofit Package impact the ability to do your job (positively and/or negatively)?

Section II – 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.

12. Did you ever receive an EEBL alert or warning?
   - ❑ No *(skip to Section III)*
   - ❑ Yes

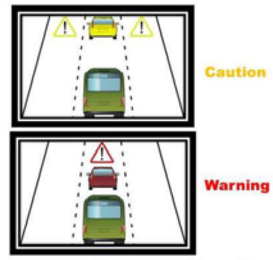
Thinking about the EEBL application, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
17. It was clear *why* the EEBL issued an alert or warning when it did (i.e., there was another vehicle ahead that was stopped or that was braking hard).	1	2	3	4	5	6	7
Comments:							
19. The EEBL was effective at drawing attention to the presence of a vehicle ahead that was stopped or was braking hard.	1	2	3	4	5	6	7
Comments:							
22. I would like EEBL to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

24. How often did you receive EEBL alerts or warnings that you felt were incorrect (i.e., there was no danger present)?
   - ❑ Every day
   - ❑ Few times per week
   - ❑ Few times per month
   - ❑ Very rarely

25. Please describe anything that you would change about the EEBL application?

Section III – 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.

26. Did you ever receive an FCW alert or warning?
    - ❑ No *(skip to Section IV)*
    - ❑ Yes

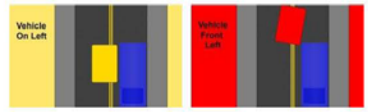
Thinking about the FCW application, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
31. It was clear *why* the FCW issued an alert or warning when it did (i.e., there was another vehicle ahead that was stopped or moving more slowly than the bus).	1	2	3	4	5	6	7
Comments:							
33. The FCW was effective at drawing attention to the presence of a vehicle ahead that was stopped or was moving slowly.	1	2	3	4	5	6	7
34. The FCW was easy to use and understand.	1	2	3	4	5	6	7
Why:							
36. I would like FCW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

38. How often did you receive FCW alerts or warnings that you felt were incorrect (i.e., there was no danger present)?
    - ❑ Every day
    - ❑ Few times per week
    - ❑ Few times per month
    - ❑ Very rarely

39. Please describe anything that you would change about the FCW application?

<u>Section IV – Vehicle Turning Right Warning (VTRW)</u>



VTRW helps to warn drivers of a vehicle pulling up next to the bus from the rear that potentially may turn in front of the bus while at a bus stop.

40. Did you ever receive a VTRW alert or warning?
- ❑ No *(skip to Section V)*
- ❑ Yes

Thinking about the VTRW application, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
45. It was clear *why* the VTRW issued an alert or warning when it did (i.e., there was another vehicle pulling up next to the bus on the left side).	1	2	3	4	5	6	7
Comments:							
47. The VTRW was effective at drawing attention to the presence of a vehicle pulling up on the left side.	1	2	3	4	5	6	7
Comments:							
48. The VTRW was easy to use and understand.	1	2	3	4	5	6	7
Why:							
50. I would like VTRW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

53. Please describe anything that you would change about the VTRW application?

<u>Section V – Curve Speed Warning (CSW)</u>

CSW helps to warn drivers that a curve is being taken at too high of a speed.

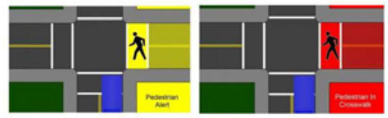
54. Did you ever receive a CSW alert or warning?
   - ❑ No *(skip to Section VI)*
   - ❑ Yes

Thinking about the CSW application, please indicate the extent to which you agree or disagree with each statement. *(Circle <u>one</u> response for <u>each</u> question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
59. It was clear *why* the CSW issued an alert or warning when it did (i.e., the bus was being driven potentially too fast through the curve).	1	2	3	4	5	6	7
Comments:							
61. The CSW was effective at drawing attention to the situation in which the curve was being taken at a high speed.	1	2	3	4	5	6	7
Comments:							
64. I would like CSW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

67. Please describe anything that you would change about the CSW application?

Section VI– Pedestrian in Crosswalk Warning (PCW)



PCW helps to warn drivers of a pedestrian in the second crosswalk that the bus will pass through as it turns at an intersection.

68. Did you ever receive a PCW alert or warning?
    - ❑ No *(skip to Section VII)*
    - ❑ Yes

69. What did you like *most* about the PCW application?

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70. What did you like *least* about the PCW application?

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71. Approximately how many PCW alerts and warnings did you receive during the demonstration?
    - ❑ <5
    - ❑ 6-9
    - ❑ 10+

Thinking about the PCW application, please indicate the extent to which you agree or disagree with each statement. *(Circle one response for each question below. Provide additional comments as needed.)*

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
72. The difference between a PCW alert and warning was clearly evident on the display.	1	2	3	4	5	6	7
Comments:							
73. It was clear *why* the PCW issued an alert or warning when it did (i.e., there was a pedestrian in the second crosswalk or standing at the edge of the crosswalk).	1	2	3	4	5	6	7

STATEMENT	Strongly Disagree			Neither Agree nor Disagree			Strongly Agree
Comments:							
74. I trusted the PCW alerts and warnings.	1	2	3	4	5	6	7
Comments:							
75. The PCW was effective at drawing attention to the presence of a pedestrian in the second crosswalk.	1	2	3	4	5	6	7
Comments:							
76. The PCW was easy to use and understand.	1	2	3	4	5	6	7
Why:							
78. I would like PCW to be installed on all of the buses that I drive.	1	2	3	4	5	6	7
Comments:							

80. How often did you receive PCW alerts or warnings that you felt were incorrect (i.e., there was no danger present)?
- ❑ Every day
- ❑ Few times per week
- ❑ Few times per month
- ❑ Very rarely

81. Please describe anything that you would change about the PCW application?

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Section VII – Driver Information

82. What is your current operator category?
    - ❑ Fulltime
    - ❑ Student

83. How often did you drive a TRP-equipped bus?
    - ❑ Multiple times per week
    - ❑ Once per week
    - ❑ A couple times per month
    - ❑ Once per month
    - ❑ Less than once per month

84. Would you want similar Connected Vehicle applications on your personal vehicle?
    - ❑ No
    - ❑ Yes

Please offer any additional comments, suggestions, or other observations.

Thank you for your participation. Please return completed survey to Dillon Funkhouser.

Appendix E. Focus Group Questions

Model Deployment Focus Group Questions

Overall Usability

- What issues did you encounter when trying to read and interpret alerts/warnings on the display?
- How helpful were the audio notifications that accompanied the alerts/warnings?
- How well did the display integrate with the remainder of the driver area?

Overall Perceived Safety Benefits

- How much of an impact did the alerts/warnings have in notifying you of potentially unsafe situations?
- How likely would widespread use of TRP improve transit safety related to vehicle accidents?

Overall Understandability

- How easily could you distinguish between the alerts/warnings among the five applications?
- How beneficial was the training that was provided about using TRP? How necessary was it?
- How helpful was the TRP Quick Reference card that summarized the various alerts/warnings?

Overall Desirability

- What is your level of interest in having TRP installed on buses that you drive?
- How valuable would it be to have TRP installed on as many buses as possible?

Overall Security and Privacy

- What data privacy concerns do you have regarding TRP?
- What security concerns do you have regarding TRP?

Individual Safety Applications (questions were repeated for each application)

- How easy was it to distinguish between an alert and a warning?
- How often did you receive alerts/warnings that you believed to be false alarms? How did these occurrences affect your response to other alerts/warnings?
- What improvements could be made to increase the usefulness of alerts/warnings?

- Were the alerts/warnings provided in sufficient time to warn of potentially unsafe situations?
- What level of trust did you place on the alerts/warnings that were displayed? How did you respond upon receiving them?
- How large an impact could increased use of the TRP have in improving transit safety related to vehicle accidents?
- Were the alerts/warnings provided in sufficient time to warn of potentially unsafe situations?
- What level of trust did you place on the alerts/warnings that were displayed? How did you respond upon receiving them?
- How large an impact could increase use of the TRP have in improving transit safety related to vehicle accidents?
- What issues did you have understanding the meaning of the displayed alerts/warnings and knowing how to respond to them?
- How much training of new drivers would be needed for them to know how to correctly respond to displayed alerts/warnings?
- How willing would you be to drive buses equipped with on a regular basis?
- What changes to would increase your interest in having it installed on your buses?

Redeployment Focus Group Questions

Overall Usability

- What issues did you encounter when trying to read and understand cautions/warnings on the display?
    - How beneficial was the increased display time?
- How helpful were the verbalized cautions/warnings that accompanied the display?
- How well did the display fit into the driver area on the bus?

Overall Perceived Safety Benefits

- How much of an impact on your driving did the cautions/warnings have when notifying you of potentially unsafe situations?
- Do you think widespread use of the TRP system would improve transit safety related to vehicle accidents?

Overall Understandability

- How easily could you distinguish between the cautions/warnings among the five applications?
- What issues did you have hearing or understanding the verbalized cautions/warnings?
- How beneficial was the training that was provided about using the TRP system? How necessary was it?
- How helpful was the TRP Quick Reference card that summarized the various cautions/warnings?

Overall Desirability

- What is your level of interest in having the TRP system installed on buses that you drive?
- How valuable do you think it would be to have the TRP system installed on as many buses as possible?

Overall Security and Privacy

- Did you have any data privacy concerns regarding the TRP system?
- Did you receive any feedback or comments from riders regarding the TRP system?

Pedestrian in Signalized Crosswalk Warning and Vehicle Turning Right in Front of Bus Warning (questions were repeated for each application individually)

- How easy was it to distinguish between a PCW caution and a PCW warning?
- What issues did you have understanding the meaning of the PCW cautions/warnings and knowing how to respond to them?
- How much training of new drivers would be needed for them to know how to correctly respond to PCW cautions/warnings?
- How often did you receive PCW cautions/warnings that you believed to be false alarms? How did these occurrences affect your response to other cautions/warnings?
- How do you feel the frequency of false alarms changed since last summer?
- Did you receive the PCW Ready screen when driving through the intersection (i.e., not turning)?
- Was the PCW Ready screen deactivated once your bus was halfway through the crosswalk?
- What improvements could be made to increase the usefulness of PCW cautions/warnings?
- Did you experience situations where you felt you should have received a PCW Ready screen or caution/warning but did not?
- What improvements could be made to increase the usefulness of PCW cautions/warnings?
- Did you experience situations where you felt you should have received a PCW Ready screen or caution/warning but did not?
- Were the PCW cautions/warnings provided in enough time to warn of potentially unsafe situations?
- What level of trust did you place on the PCW cautions/warnings that you received? How did you respond upon receiving them?
- How willing would you be to drive buses equipped with PCW on a regular basis?
- What changes to PCW would increase your interest in having it installed on your buses?

Other Applications

- What problematic issues did you experience understanding or using the FCW, EEBL, and CSW applications?
- What level of trust did you place on the FCW/EEBL/CSW cautions/warnings that you received?
- What changes to FCW/EEBL/CSW would increase your interest in having them installed on your buses?

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