Connected Commercial Vehicles—Integrated Truck Project

Final Report

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This is the final report for the Connected Commercial Vehicles—Integrated Truck Project. The Connected Commercial Vehicle Team is led and managed by Battelle and includes the University of Michigan Transportation Institute (UMTRI), Mercedes-Benz Research & Development North America, Inc. (MBRDNA), DENSO International America, Inc.—North America Research and Development, California Office, Daimler Trucks North America (DTNA), and Meritor WABCO.

16. Abstract

Connected vehicle wireless data communications can enable safety applications that may reduce crashes, injuries, and fatalities suffered on our roads and highways, as well as enabling reductions in traffic congestion and effects on the environment. As a critical part of achieving these goals, the USDOT contracted with a Team led by Battelle to integrate and validate connected vehicle on-board equipment (OBE) and safety applications on selected Class 8 commercial vehicles and to support those vehicles in research and testing activities that provide information and data needed to assess their safety benefits and support regulatory decision processes.

This final report summarizes all of the activities and accomplishments of this project. Hardware and software were developed to adapt safety applications to commercial vehicles. Stages of testing included benchtop, test track, driver acceptance clinics, and support for the Safety Pilot Model Deployment. Outreach consisted of a demonstration at a trade show, presentations at meetings, and other activities.

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Executive Summary

Connected vehicle telecommunications for vehicle data can transform travel in North America, enabling major reductions in crashes, injuries, and fatalities suffered on our roads and highways, as well as enabling reductions in traffic congestion and effects on the environment. Under this Connected Commercial Vehicle Safety Applications Development Program, the United States Department of Transportation (USDOT) has contracted with a team led by Battelle to integrate connected vehicle onboard equipment (OBE) and safety applications on Class 8 commercial vehicles and to support those vehicles in research and testing. The project provided information and data needed to assess the applications' safety benefits and support regulatory decision processes.

This report summarizes all of the work performed in this 2 1/2-year project. Team members began with OBE that had been designed for light vehicles and adapted it to commercial vehicles. The hardware for the OBE was DENSO's new generation of the Wireless Safety Unit, the WSU 1.5. Software for safety applications was modified to account for the size differences of tractor semitrailer combinations. The OBE was integrated with newly manufactured Freightliner Cascadia tractors painted red, white, and blue for easy reference. (A fourth tractor was instrumented for use on a different project.) Four vehicle-to-vehicle (V2V) safety applications that had been originally developed by Mercedes-Benz for light vehicles were implemented on the tractors:

- Intersection Movement Assist (IMA)
- Forward Collision Warning (FCW)
- Emergency Electronic Brake Light (EEBL)
- Blind Spot Warning, Lane Change Warning (BSW/LCW)

Two vehicle-to-infrastructure (V2I) applications were implemented:

- Bridge Height Inform (BHI)
- CurveSpeed Warning (CSW)

CSW is also available on light vehicles; BHI is new to commercial vehicles.

Each tractor was outfitted with a Data Acquisition System (DAS) by the University of Michigan Transportation Research Institute (UMTRI) to record the truck's motion as well as all messages transmitted and received by the OBE.

The integrated trucks were subjected to a series of tests. Benchtop verification of the equipment at installation ensured that subsequent outdoor testing would be productive. The V2V safety applications' functioning was demonstrated in a series of 25 scenarios with one or two other vehicles on a test track. Driver Acceptance Clinics at two sites introduced over 100 professional truck drivers to the technology. Their opinions were positive, and their suggestions and cautions have been documented. The tractors with all six safety applications active participated in the year-long Safety Pilot Model Deployment in Ann Arbor, Michigan, demonstrating interoperability with light vehicles in a real-world setting.

Outreach was a part of this project. Beginning with a booth and truck demonstrating the FCW safety application at the ITS World Congress in Orlando in 2011, the work was publicized to the trucking and ITS communities. Recruiting for the Driver Acceptance Clinics included posters at terminals and a web site that explained the technology. Team member Meritor WABCO displayed posters and distributed flyers promoting the technology at its booth at trade shows.

Work remains to fully develop connected vehicle technology for commercial vehicles. In this successful first step, the Basic Safety Message (BSM) broadcast by the commercial vehicle described it as a single long block. Many options for indicating its articulation in curves were considered, but consensus of many stakeholders, including the light vehicle community, is needed to decide on the best course. A number of differences between light and commercial vehicles have been listed. They range from the size of the vehicle to the operation of commercial vehicles. These differences suggest new safety applications unique to commercial vehicles that would enhance safety, mobility, and the environment.

Chapter 1 Introduction

The purpose of the project was to take technology that has been developed for light passenger vehicles and integrate it with newly manufactured commercial motor vehicles, specifically a truck tractor for pulling a semitrailer. Vehicles equipped with this technology broadcast radio signals indicating their position and other information to surrounding vehicles. This information is intended to help drivers avoid crashes. The project evaluated the technology in a number of ways.

Description of the Overall Project

Connected vehicle telecommunication systems for vehicle data have the potential to transform vehicle travel in North America, enabling major reductions in injuries and fatalities suffered on our roads and highways, as well as enabling reductions in traffic congestion and effects on the environment. As a critical part of achieving these goals, the USDOT wishes to apply the successful experience with connected vehicle technology implementation on light vehicles to commercial vehicles; and to demonstrate the performance, interoperability, and safety benefits of the technology in mixed light and commercial vehicle environments. Under this Connected Commercial Vehicle Safety Applications Development Program, the USDOT contracted with a Team led by Battelle to integrate and validate connected vehicle on-board equipment (OBE) and safety applications on selected Class 8 commercial vehicles and to support those vehicles in research and testing activities that provide information and data needed to assess their safety benefits and support regulatory decision processes.

The team adapted safety applications that had been developed for light vehicles. While maintaining the basic functionality of the applications, parameters were adapted to the particular needs of large commercial vehicles. A new generation of the hardware was used to enhance integration with the commercial vehicle. Two Dedicated Short-Range Communication (DSRC) antennas, one each on the left and right side mirrors on the cab, proved to be sufficient for transmitting and receiving around the tractor and trailer. Icons to depict the hazards in each safety application were developed specifically for commercial vehicles. They were displayed on a screen above the parking brake controls, and the sounds came through the cab's own speakers. Two new safety applications specifically for commercial vehicles were developed.

The first demonstration to occur was at the ITS World Congress in Orlando, Florida, with light vehicles responding to messages broadcast from a commercial vehicle [1]. The fully functioning installations were demonstrated at the end of Task 4 [4]. Driver Acceptance Clinics were conducted at two sites to learn the opinions and suggestions of professional truck drivers who were previously unfamiliar with the technology. At the same time that preparations for the Driver Clinics were underway, USDOT staff were conducting Interoperability Testing. Finally, the equipped tractors were delivered to Ann Arbor, Michigan, for testing in revenue service during the Model Deployment, where they performed as intended. The three equipped tractors were delivered to the Vehicle Research and Test Center for continued testing at the end of this project.

Description of the Technologies

The heart of the technology is a radio and computer on a vehicle. It determines the vehicle's location using Global Positioning System (GPS) and broadcasts its location to surrounding vehicles ten times a second. The technology has matured to the point that these functions are performed in a compact, field hardened wireless safety unit (WSU). A special radio protocol called Dedicated Short-Range Communication (DSRC) uses the 5.9 GHz band to transmit signals, either from a vehicle to a vehicle (V2V) or between vehicles and the infrastructure (V2I).

The Basic Safety Message (BSM) that is transmitted to surrounding vehicles includes not only the position of the vehicle, but also its speed, heading, size, whether the brake lights are on, and more. Other vehicles nearby can use this information to determine whether they are on a possible collision course and advise their drivers. A "safety application" is the name of the computer logic on the receiving vehicle that determines whether to inform the driver of a potential hazard (for example, a vehicle in a blind spot) or to warn the driver of an imminent hazard (for example, of a stopped vehicle ahead).

Retrofit Safety Device (RSD) Kit and Transit Projects

A separate contract, conducted in parallel with this one, developed safety applications for installation in a previously manufactured truck tractor. The Retrofit Safety Device (RSD) was designed and built as a kit by a nearly identical project team and delivered to USDOT for installation. The safety applications in the RSD project were essentially identical to those in this Integrated Truck project. The devices went through similar testing: bench-top checkouts, functional tests in carefully planned scenarios on a closed track, and participation in the Model Deployment in Ann Arbor, Michigan. The RSD project is documented in a separate report.

Another Battelle-led team prepared transit buses that participated in the Model Deployment. Battelle developed, demonstrated, and deployed transit-specific applications.

Team

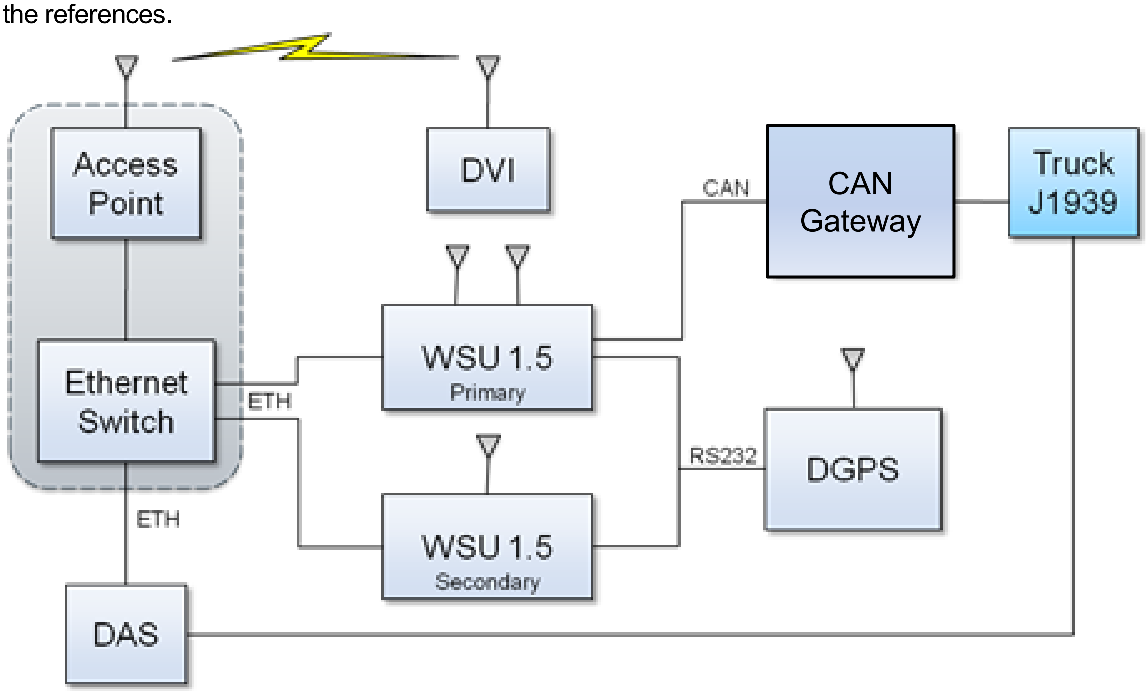
The prime contractor for the Connected Commercial Vehicles—Integrated Truck project was Battelle. The project was conducted under the direction of the Intelligent Transportation Systems Joint Program Office with input from other agencies in the USDOT.

- Battelle
  - Managed and coordinated the program
  - Led the Driver Clinics
  - Supported systems and DAS Integration
  - Consulted on safety applications requirements
- University of Michigan Transportation Research Institute (UMTRI)
  - Supported safety applications requirements and development
  - Tested and evaluated the performance of safety applications
  - Refined, installed, and supported Data Acquisition Systems

- Mercedes-Benz Research and Development North America, Inc. (MBRDNA)
    - Led the integration and enhancement of CCV OBEs
    - Led DSRC antenna placement assessments
    - Led safety applications development for CCVs
- DENSO International America, Inc.—North America Research and Development, California Office
    - Consulted and advised on OBE integration and DSRC antennas placement
- Daimler Trucks North America (DTNA)
    - Supported integration of OBE with CMV J1939 CAN bus
    - Consulted on safety applications requirements for commercial vehicles
    - Drafted tractor specifications
- Meritor WABCO
    - Consulted and advised on integration of collision avoidance and safety applications in commercial vehicles,
    - Consulted and advised on Driver Clinic logistics
    - Contributed to project outreach.

Chapter 2 Components of the System

The Onboard Equipment (OBE) had hardware and software patterned after the light vehicle counterpart. Components of the OBE supported its many interfaces, as illustrated in Figure 2-1. A pair of DSRC antennas broadcast and received BSMs. Communication with the host vehicle was through its J1939 data bus. Messages to be displayed by the Driver Vehicle Interface (DVI) were transmitted via Ethernet. All communication by the OBE and much information directly from the vehicle itself was stored by a Data Acquisition System (DAS) to support testing and analysis. This section describes these components of the system and explains the operation of the safety applications. Complete specifications of the respective systems are in separate task reports listed in the references.



MBRDNA

Figure 2-1. Architecture of the CCV-IT OBE, including its interfaces to the vehicle, DVI, and DAS.

Onboard Equipment (OBE)

The platform development portion of the CCV Safety Applications Development project is structured largely as an adaptation of a pre-existing system developed over multiple projects for Light Vehicles. System development was initiated in 2006 by the Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications 2 (VSC2) Consortium (Ford Motor Company, General Motors Corporation, Honda R&D Americas, Inc., Mercedes-Benz Research and Development North America, Inc., and Toyota Motor Engineering & Manufacturing North America, Inc.) for the U.S Department of Transportation (USDOT) Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) project. Development continued in the Vehicle Safety Communications – Applications (VSC-A) project based on the platform used for the CICAS-V project. The platform is again being used and modified for vehicle safety communications research in the Vehicle-to-Vehicle – Safety Pilot (V2V-SP) project. The architecture and design of this platform includes the ability to add applications in the future.

The OBE System architecture is shown as a block diagram in Figure 2-1.

Complete documentation of the OBE is in a separate report [7]. Installation of the OBE equipment to perform the safety applications and the DAS to record the performance is described in Vehicle Build and Test Plan [5].

Hardware

A DENSO product called the Wireless Safety Unit (WSU) functioned as the heart of the OBE in this project. The particular version used for the CCV-IT project was the WSU1.5 (Figure 2-2), which is a combination computing and communications platform designed to accommodate test and evaluation of the emerging Intelligent Transportation Systems (ITS) protocol and related safety, mobility, and productivity applications. It consists of a custom single board computer with various automotive and communications interfaces. Its size is 140 x 120 x 30 mm. A summary of the WSU 1.5 attributes is in Table 2-1.

The WSU1.5 includes a 5.9 GHz DSRC radio, an applications processor, and a custom single board computer as a platform for V2X communications and applications research and development. Included are connections for power, ignition sense, RS-232 serial data, GPS serial NMEA and 1 pulse/second timing, 100BaseT Ethernet, two USB1.1 ports, three general purpose inputs, one general purpose output, supply ground, and two CAN2.0 ports. The internal WSU1.5 configuration file includes an element for entering the physical three-dimensional offset between the location of the GPS antenna and the geometrical center of the vehicle.

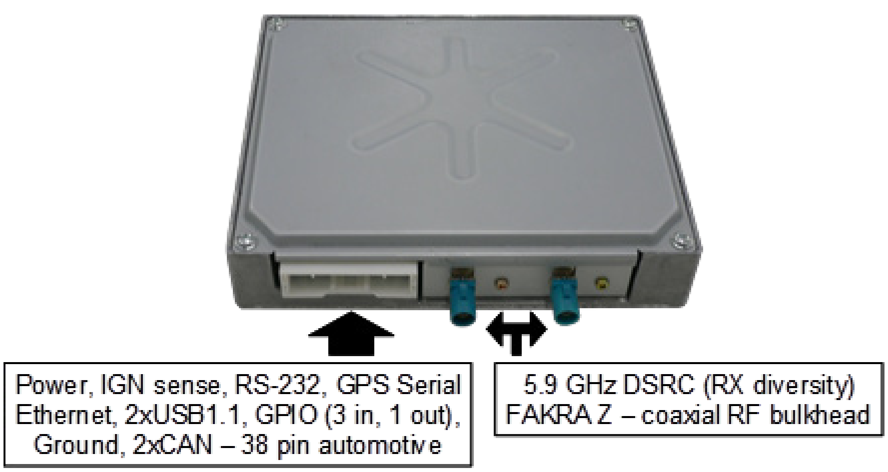


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Figure 2-2. The OBE included two WSU1.5 units.

Table 2-1. Attributes of the WSU 1.5.

Attribute	Description
Operating Mode	WAVE (P1609.3, P1609.4, 802.11p)
Frequencies	5.85 - 5.925 GHz (ITS-RA band)
Data Rates	3 - 27 Mbps (10 MHz channels) 6 - 54 Mbps (20 MHz channels)
Transmission Output Power	10 to 18 dBm (rate-dependent), measured at antenna connector
Ambient Operating Temperature	-30 to +65 °C
Enclosure	System ground metal case

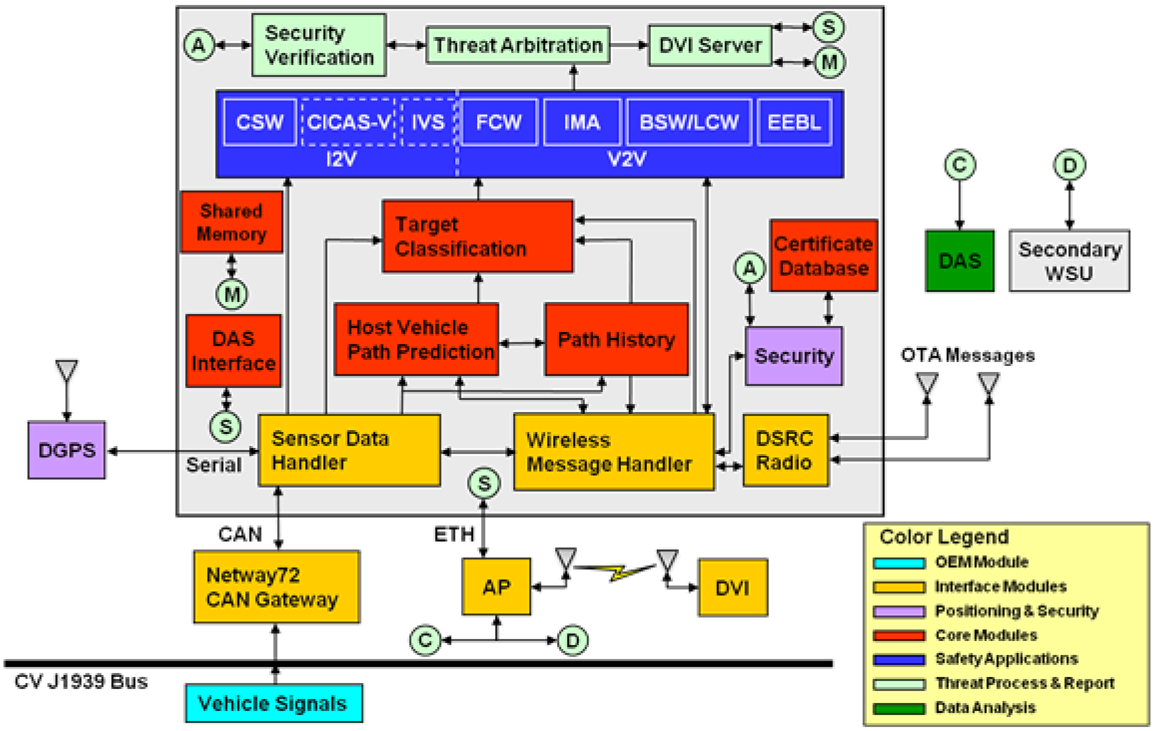
DENSO

Figure 2-1 showed that the OBE included two WSUs. The primary WSU contained the software for the safety applications using vehicle-to-vehicle communication. It communicated with the host vehicle, transmitted and received over-the-air (OTA) messages through the DSRC antenna pair, and instructed the DVI to display messages when needed. Operating in continuous or single-channel mode, it functioned almost independently of the secondary WSU. The secondary WSU operated as an alternating or channel-switching radio. It received the IEEE1609.2 certificate management commands and the certificate databases. The secondary WSU also received the Traveler Information Messages (TIMs) from roadside equipment (RSE) for the Curve Speed Warning (CSW) applications during the Model Deployment. The main connection between the two WSUs was for exchanging security certificates.

Software

The WSU1.5 Operating System and file system is Linux. The DENSO Software Services provides an Application Programming Interface (API) to enable applications to obtain data from the GPS receiver and the CAN Bus. The API also enables an application to configure the 5.9 DSRC radio parameters and to transmit and receive data. The Security Interface Services supports the signing and verification of WSMs in accordance with IEEE P1609.2. The safety applications sit atop this WSU Software Services architecture.

The software structure of the primary WSU is illustrated in Figure 2-3. It is similar to the OBE installations used for light vehicle V2V crash avoidance. The Commercial Vehicle Safety Communications Application (CVSCA) modules consist of system framework modules and application modules. The system framework modules interface to external equipment, calculate data to support the CVSCA application modules, and support the user interface. The application modules evaluate potential safety threats based on inputs from the system framework modules. The application modules consist of five Vehicle to Vehicle (V2V) applications developed or modified under the CCV program.



DENSO

Figure 2-3. Functional software architecture of the primary WSU.

GPS

Vehicle position was determined through a commercially available DGPS receiver. The device provides 10-Hz messages and pulse timing to the WSU via RS-232.

Vehicle Interface

Vehicle data from the J1939 bus was accessed using a commercially available interface device. The device was programmable via the USB port.

Driver-Vehicle Interface (DVI)

The WSU controls the DVI output using UDP via a wireless Access Point. A customized iPad2, as pictured in Figure 2-4 below, hosts the display of visual information to the driver and supports four-channel audio. The cab's existing speakers were used, providing directional audio warnings. The display for the driver was an iPad as shown in Figure 2-4.

Battelle

Figure 2-4. Messages for the safety applications were displayed on the iPad to the right of the steering wheel. (The mechanism above the display is a lock.)

DSRC Antenna

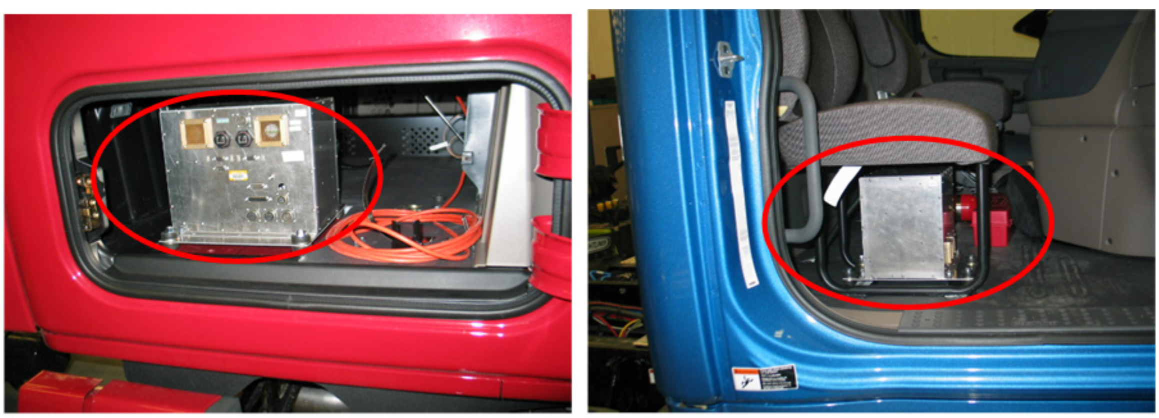
Figure 2-5 is a close-up of the right-side antenna mount on the white tractor. The DSRC antenna is circled. An identical antenna were mounted on the opposite side of the vehicle. These two antennas were used by the primary WSU. The secondary WSU used a single sharkfin DSRC antenna, identical to those on light vehicles.

Battelle

Figure 2-5. The DSRC antenna on the right side of the tractor is circled.

Data Acquisition System (DAS)

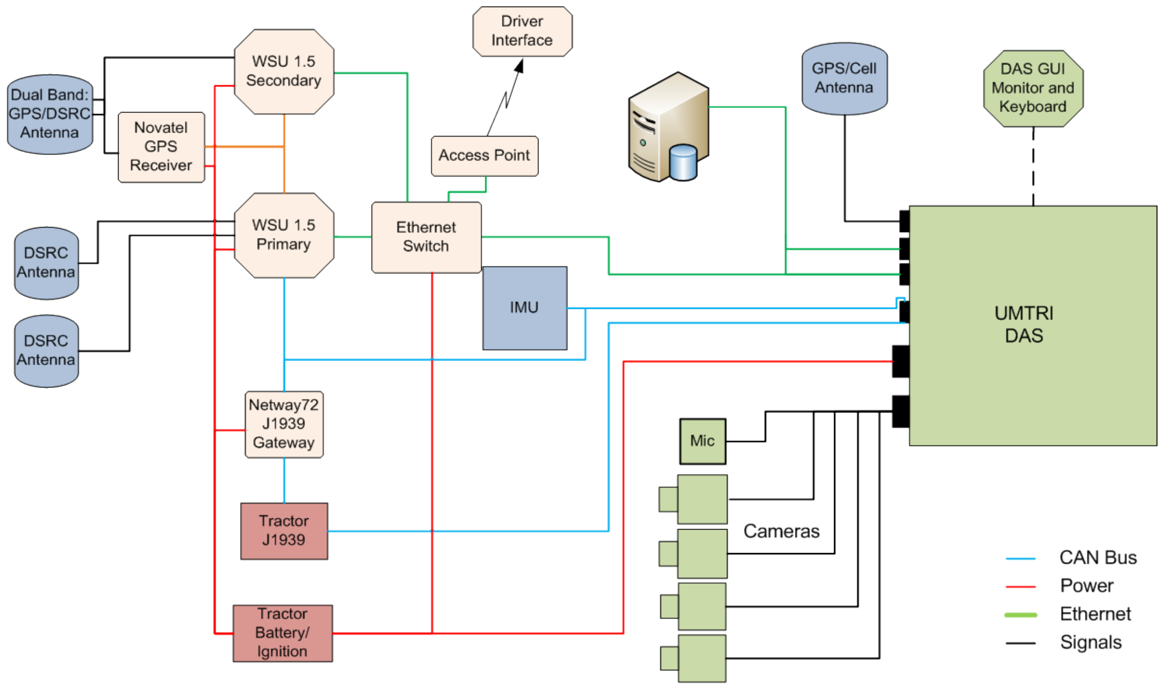
The activity of the OBE and the vehicle was recorded by a Data Acquisition System (DAS) built by UMTRI. Figure 2-6 shows the DAS main units were installed, and Figure 2-7 is a block diagram of the DAS and its connections. The design of the DAS, as well as documentation of testing it and instructions for operating it are in a separate report [3].



UMTRI DAS—Sleeper (Mid-roof) UMTRI DAS—Day Cab

UMTRI

Figure 2-6. The DAS was mounted in a cargo compartment in the sleeper cabs (left) and under the passenger seat in the day cab (right).



UMTRI

Figure 2-7. The DAS recorded data from the OBE and from sensors of the vehicle's motion, including video cameras.

Vehicles

Four tractors were outfitted with the CCV-IT equipment. All were Freightliner Cascadia model year 2012. They were different body styles: a day cab, a mid-roof sleeper, and a high-roof sleeper. The three tractors for this project were painted red, white, and blue, as shown in Figure 2-8, to easily identify them. A fourth tractor, a high-roof sleeper painted silver, was outfitted for use in another USDOT program. A summary of the specifications for the tractors is in Table 2-2.

Tractors were tested at various times with 53-foot and 48-foot dry van trailers and with a 40-foot intermodal container on a chassis. Trailers were empty during testing.

Table 2-2. Summary of specifications for the tractors.

Color	Blue	Red	White
Body Style	day cab	48-in. sleepercab	72-in. raised roof sleepercab
Factory Weight, lb			
front	8,995	9,650	10,077
rear	6,659	6,989	7,174
total	15,654	16,639	17,251
Wheelbase, in.	178	210	228
Engine	12.8L, 450 HP @ 1800 rpm, 1550 lb-ft @ 1100 rpm		
Front Suspension	12,000 lb capacity taperleaf		
Rear Suspension	40,000 lb capacity airliner tandem		
Brakes	WABCO 6S/4M ABS with traction control		
Transmission	Eaton Fuller Ultrashift		

Battelle

UMTRI

Figure 2-8. The CCV-IT equipment was installed on Red, White, and Blue Freightliner Cascadia tractors of three different body styles.

Safety Applications

Six applications were developed for commercial vehicles by MBRDNA as part of this project:

- Intersection Movement Assist (IMA)
- Forward Collision Warning (FCW)
- Emergency Electronic Brake Light (EEBL)
- Blind Spot Warning, Lane Change Warning (BSW/LCW)
- Bridge Height Inform (BHI)
- CurveSpeed Warning (CSW)

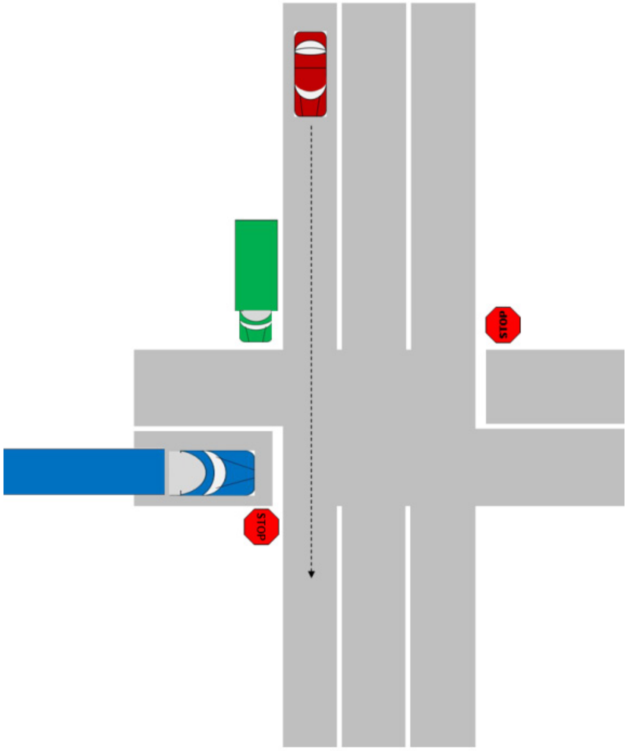
This section describes the safety applications qualitatively. They are fully defined in the Applications Requirements Document [9]. Descriptions of the applications are illustrated here with both a schematic diagram and a photograph. They are accompanied by images of the messages that were displayed to the driver. The images were displayed on the iPad mounted above the parking brake controls as shown in Figure 2-4. Sounds for the alerts originated in the iPad and were played through the tractor's stereo speakers. The photographs were taken during the Driver Acceptance Clinic in Alameda, California.

Each of the descriptions includes a brief explanation of how the parameters for the application were changed from the corresponding light vehicle application to be appropriate for commercial vehicles.

IMA: Stopped Truck Enters an Intersection with another Vehicle Approaching

The first application was the Intersection Movement Assist (IMA). The typical scenario served by this application is a truck waiting at a stop sign. As shown in Figure 2-9 and Figure 2-10, another vehicle may obstruct the drivers's view of a light vehicle approaching from the left. If the truck starts to move forward, the IMA application will issue a warning to the truck driver. The images that were displayed for the IMA alert are shown in Figure 2-11.

This application on a light vehicle begins to warn as soon as the driver's foot is removed from the brake pedal because an automatic transmission vehicle can begin to move when the brake is released. In contrast, the application on a commercial vehicle warns only when the accelerator is pushed and the vehicle speed begins to increase. In addition, the estimate of the commercial vehicle's acceleration capability is less than a light vehicle's, and the commercial vehicle parameters allow a greater driver response time. These two changes provide the commercial vehicle a larger gap in cross traffic.



Battelle

Figure 2-9. IMA: An equipped commercial vehicle rolls into the intersection with cross traffic approaching.

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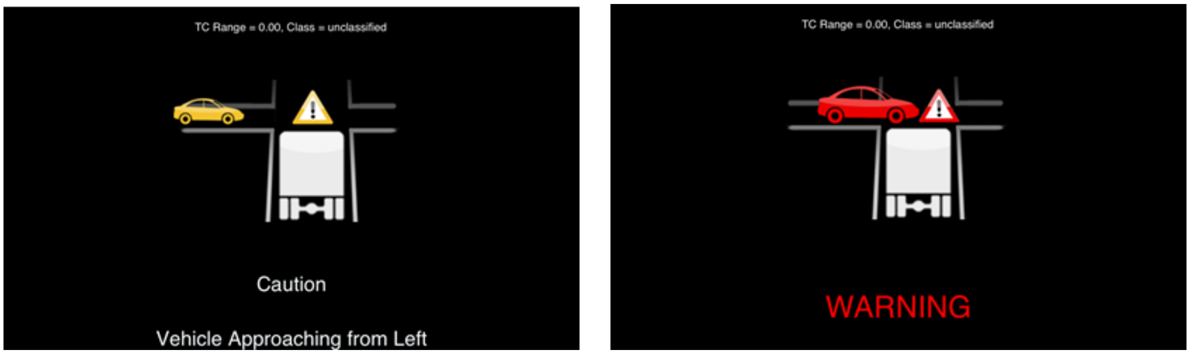
Figure 2-10. IMA: The white tractor is stopped at a stop sign. The driver's view of the approaching red vehicle is blocked by the yellow truck.



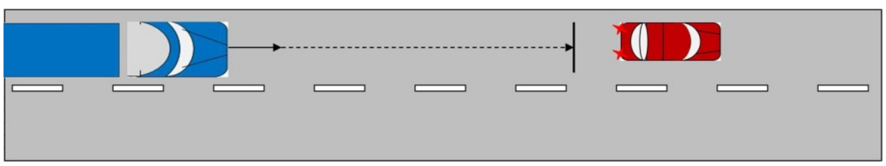
MBRDNA

Figure 2-11. The iPad by the driver displayed the image on the left for a less urgent "inform" level alert and the image on the right for a more urgent "warn" level alert.

FCW: Truck Encounters a Stopped Vehicle in the Same Lane

The scenario for the Forward Collision Warning (FCW) consists of two vehicles traveling in the same direction. Ahead of the truck in its lane is a stationary light vehicle, as illustrated in Figure 2-12, and Figure 2-13. Figure 2-14 shows the two icons shown for the FCW alerts.

Even under the best conditions, commercial vehicles cannot brake as well as light vehicles. Therefore, the FCW implementation on a commercial vehicle monitors farther ahead for stopped vehicles. The parameter for the truck's deceleration is lowered, and increased driver response time is allowed. The application delivers alerts to a truck driver earlier than it would to a light vehicle driver.



Battelle

Figure 2-12. FCW: The light vehicle is stopped in the same lane as the truck.

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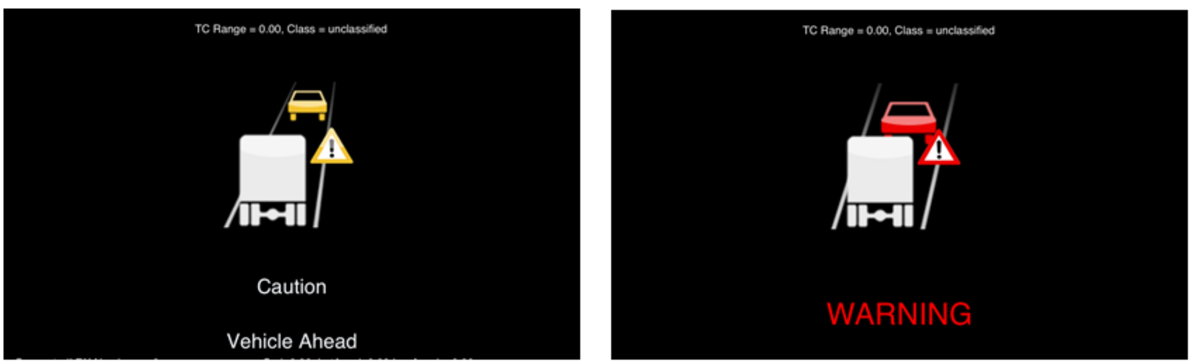
Figure 2-13. FCW: The red vehicle has stopped in the path of the white host vehicle.



MBRDNA

Figure 2-14. The "inform" level (left) and "warn" level (right) images for the FCW alert.

EEBL: Driver's View of a Slowing Vehicle is Blocked

The Emergency Electronic Brake Lights (EEBL) application applies to a suddenly slowing vehicle ahead of the truck. The EEBL is sensitive to vehicles farther ahead than the FCW. If the braking vehicle is in the same lane as the truck, the EEBL delivers a warning to the driver that is audible but less intensive than the FCW warning. If the slowing vehicle is ahead but in a different lane than the truck, the EEBL delivers only a silent alert.

In an example EEBL scenario, a small truck blocks the driver's view of the slowing vehicle. The light vehicle suddenly applies its brakes, and the small truck changes lanes to avoid the stopped car. The paths of the vehicles are shown in Figure 2-15, and Figure 2-16 is a photograph of the light truck making the lane change to reveal the stopped car. The EEBL application displays only one level visual alert; its image is in Figure 2-17. As with FCW, the threshold was changed to recognize that commercial vehicles cannot decelerate as well as light vehicles.

The EEBL application treats any sudden lead vehicle deceleration that exceeds a preset threshold as a potential threat to the host vehicle. The deceleration threshold is lower in commercial vehicles than in light vehicles so that truck drivers can better prepare for any slowing traffic ahead.

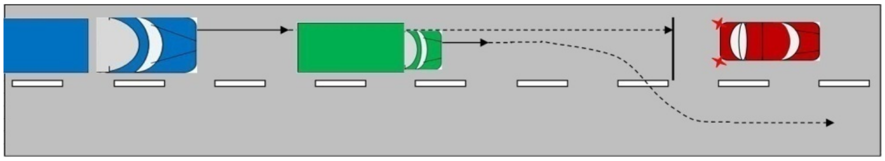


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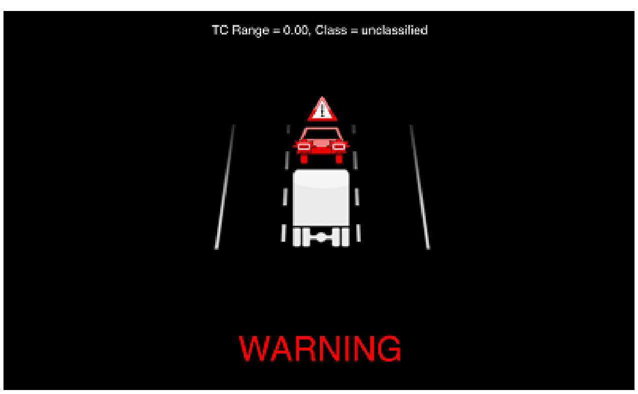
Figure 2-15. EEBL: Lane change by the green small truck reveals the slowing light vehicle.

Battelle

Figure 2-16. EEBL: The yellow blocking vehicle is pulling out of the path to reveal the recently stopped red vehicle.

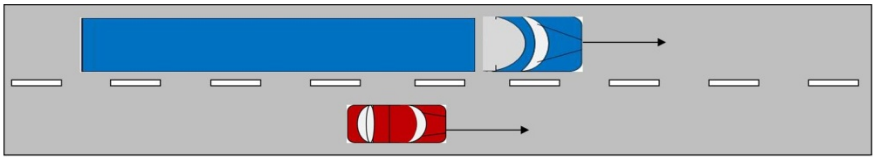


MBRDNA

Figure 2-17. This image was displayed on the iPad when the OBE issued an alert for EEBL.

BSW+LCW: Blind Spot Warning and Lane Change Warning

The BSW application provides an advisory when another vehicle enters the blind zone on either side of the equipped commercial vehicle, as shown in Figure 2-18.



Battelle

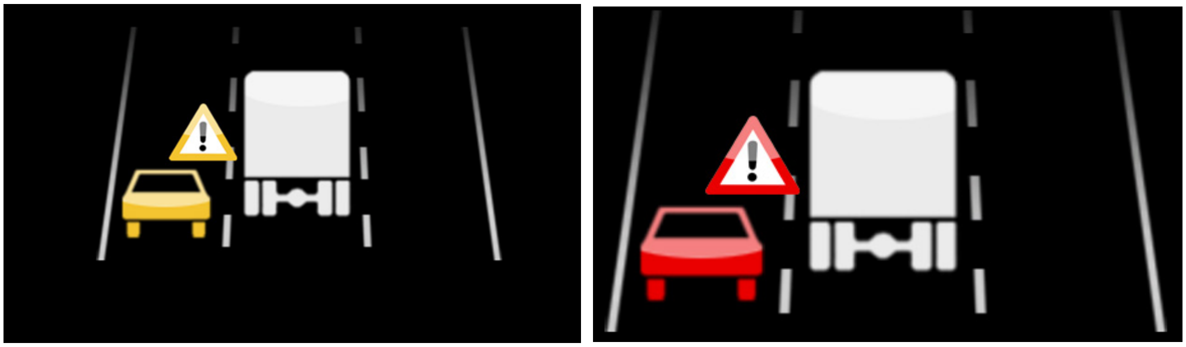
Figure 2-18. The red vehicle is in the commercial vehicle's blind spot.

The silent BSW inform message switches to an audible BSW+LCW warning when the truck driver begins to signal a lane change toward the light vehicle. Figure 2-19 is a photograph of this scenario in progress at the California clinic. The BSW and LCW icons are in Figure 2-20.

Battelle

Figure 2-19. The red vehicle is in the white commercial vehicle's blind spot.

The size and position of a blind spot on a commercial vehicle is different than it is on a light vehicle and varies with trailer configuration. A vehicle immediately ahead of the center point of a light vehicle is abreast of the driver and within the peripheral vision. In contrast, a vehicle to the right and immediately ahead of the center of a commercial vehicle is near the front of the trailer and is in fact in the position most difficult for the driver to see. Therefore, the BSW application on a commercial vehicle was designed to allow for configurable blind spots, covering areas up to the driver on the left side and extending beyond the front of the vehicle on the right side.



MBRDNA

Figure 2-20. The image on the left was displayed, without a sound, when a vehicle was in the driver's blind spot. The image on the right was displayed and a sound was played if the driver activated the turn signal toward a vehicle in the adjacent lane.

BHI: Bridge Height Inform

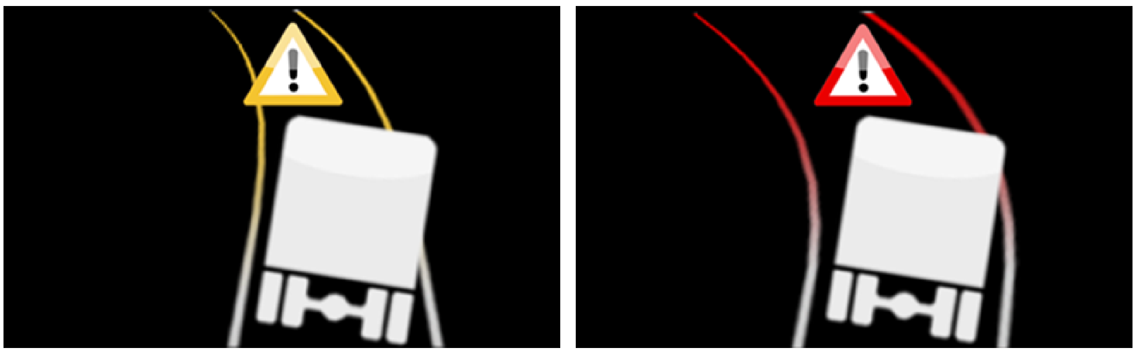
The Bridge Height Inform safety application serves the same purpose as a stationary advisory sign in advance of a low-clearance bridge or overpass. It delivers the information inside the cab so the sign cannot be obscured by another vehicle. The OBE can receive information about the location and clearance of bridges via a TIM from an RSE, or the information can be coded directly in the WSU. This application was not part of the functional tests or the driver acceptance clinics. The height and location for a pedestrian bridge in Ann Arbor, Michigan was stored in the WSU during the Model Deployment. The icon for the BHI application is in Figure 2-21.

MBRDNA

Figure 2-21. This image was displayed on the iPad to advise the driver of an approaching bridge of low clearance.

CSW: Curve SpeedWarning

The curve speed warning compares the advisory speed for a curve with the current speed of the truck and warns the driver to slow when the advisory speed is exceeded on approach. This application is advantageous over a conventional speed advisory sign in that it accounts for the truck's actual speed and it can include an audible component. The OBE can receive information about the location and curvature of roadways via a TIM from an RSE, or the information can be coded directly in the WSU. During the Model Deployment, three curves in the Ann Arbor area were outfitted with two RSEs each to inform traffic approaching from both directions. Only one of these curves was on a truck route; the others were for the light vehicles in the Model Deployment. This application was in operation during the Model Deployment, but it was not not part of the functional tests or the driver acceptance clinics. The CSW application icons are in Figure 2-22.



MBRDNA

Figure 2-22. The "inform" level (left) and "warn" level (right) images for the CSW alert.

Chapter 3 Testing

A significant portion of this equipment development project was testing. Beginning with bench-top tests and culminating in the Safety Pilot Model Deployment, the OBE and DAS went through many stages of testing and refinement. In addition to these tests conducted by the CCV-IT team itself, team members supported testing by NHTSA's Vehicle Research and Test Center (VRTC) and the safety pilot conductor.

Build Tests

The first step in testing was to ensure that the prototype safety application hardware and software components were integrated into the four tractors properly: that the systems power up, have electrical and data connectivity, and that the individual elements operate as expected and data is exchanged and collected successfully. This testing consisted of three stages:

1. Pre-installation tests of DAS functionality on the bench. These included in-vehicle wiring integrity and capture of CAN bus signals by the DAS.
2. Post-installation tests of DAS signals and integrity. These included signals in the vehicle while parked and while it was driving. They checked the transfer of data from the onboard DAS to off board servers.
3. Post-installation tests of OBE signals and integrity. These included DAS capture of WSU data packets, DSRC communication in static and dynamic tests, and OBE access to vehicle bus data and GPS.

These tests were conducted separately on each of the tractors where the CCV-IT equipment was installed. They are fully documented in a separate test report [2].

Applications Demonstration

After the installation of the components was verified, the next step was to take the tractor to a closed course and test the safety applications in coordination with a remote vehicle. This was the purpose of the Applications Performance and Functional Test [4].

These tests consisted of a comprehensive series of 25 test scenarios:

- Four to test the EEBL application
- Eight to test the FCW application
- Seven to test the BSW+LCW application
- Two (with variations) to test the IMA application.

Most of these tests were intended to demonstrate that an alert was presented to the driver in the appropriate conditions. A small number of tests were to demonstrate that the OBE did not alert when the vehicles were in a situation that was close to, but not in, a warning condition.

Testing was conducted at the Michigan Technical Research Park (MITRP) in Ottawa Lake, Michigan. MITRP includes an oval test track and associated proving grounds. Most of the tests were on the three-lane oval track; the IMA applications were at a mocked up intersection. The host vehicle (the one on which the applications were being tested) was the blue CCV-IT tractor, in combination with the 40-foot container on a chassis. The host vehicle was hitched to this trailer for the BSW+LCW scenarios, and it ran bobtail (without a trailer) for the other three scenarios. Figure 3-1 shows what the driver of the host vehicle saw during one of the FCW tests, where a different tractor was pulling the 40-foot container to block the view of the host vehicle's driver.

UMTRI

Figure 3-1. The tractor and intermodal container blocked the host vehicle driver's view of the slow-moving light vehicle before changing lanes in this test of the FCW application.

Results of the functional tests are summarized in Table 3-1. Each of the four applications was tested with a number of scenarios. Each scenario was repeated several times, and a pre-determined number of those repetitions were required to pass the test. In some of the tests for false positive alarms, the vehicles were required to maintain a certain proximity for a period of time.

At the time of the testing, the system passed 24 of 25 scenarios. One BSW+LCW scenario failed; the application could not properly handle simultaneous remote vehicles in both adjacent lanes. This was subsequently corrected. Two of 24 scenarios that had fewer runs than planned; the system warned properly in all valid runs of both scenarios.

Table 3-1. Summary of results of the application performance tests.

Application	Number of Scenarios	Number of Scenarios Passed	Comments
EEBL	4	4	Scenarios included the remote vehicle in hard braking and mild braking.
FCW	8	8	The host vehicle approached the remote vehicle that was slowing or completely stopped in straights and in curves.
BSW+LCW	7	6*	The light vehicle passed the host vehicle on the left and right on straights and on a curve. In the “false positive” tests, the light vehicle maintained a position immediately behind the host vehicle or abreast of the host vehicle two lanes away.
IMA	6	6	Scenarios were run with the host vehicle stopped and approaching the intersection at two speeds.
TOTAL	**25**	**24***	

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*The reason for the failed scenario was subsequently identified and corrected.

Driver Acceptance Clinics

More than 100 drivers, all holders of a Commercial Driver’s License (CDL) with recent professional tractor-semitrailer experience, participated in the clinics. The participants had a wide range of tenure and professional backgrounds. One clinic was held at the Transportation Research Center Inc. in East Liberty, Ohio, and one was at Alameda Point on the San Francisco Bay in California.

Participants spent about half an hour driving a new Freightliner tractor with integrated connected commercial vehicle technology. Two remote vehicles driven by professional test drivers executed scenarios that triggered four V2V safety applications in sequence. A team member in the tractor with the participant explained each scenario before it was executed and recorded immediate impressions afterward. Following the drive, each participant filled out a questionnaire, and slightly more than half were interviewed individually. The format of the clinic and the questionnaires were adapted from the light vehicle driver clinics so that results could be compared.

Battelle’s Institutional Review Board (IRB) reviewed a draft plan for the clinics early in the project, and the board reviewed amendments to the plan as it matured and questions were finalized. All team members had human subjects training as part of the preparation.

Impressions were remarkably positive. Participants readily perceived the benefits of connected commercial vehicle technology. Many offered constructive criticisms. Many drivers emphasized the importance of keeping their eyes out the window. Another frequent caution was that the system needs to be reliable and credible. Frequent, annoying alarms will not be tolerated.

Most participants expressed favorable views of the system. The most common compliments included

- "Must have"
- "At last" or "About time"
- "Better system than I expected. Very impressed."
- "The technology was excellent. The equipment was very good."
- "I like the fact that the driver is still in control, and the truck doesn't try to drive the situation."
- "I would buy this," or "I would want my employer to buy this."

Drivers shared many concerns about the system. The most common concern was that the system required drivers to look at a screen. This was written in many questionnaires and heard from almost all of the drivers selected for the interview. While most drivers saw the value of having a visual indication, they generally do not want to rely on a dashboard-located visual indicator to determine what the imminent threat is. Visual displays that bring the driver's eyes inside the cab, particularly at a critical moment, are undesirable. One driver, who was overall accepting of the technology (writing "It might save someone's life" and "Should have had this technology a long time ago. Very useful.") wrote strongly,

- "Don't like visual warning. When driving, I don't want to take my eyes off the road. This is for all tests!!"

While participants generally agreed that the audio warnings were more useful than their visual counterparts, they expressed many common concerns about the alert tones as well. Most frequently, drivers cautioned that the alert sounds should not be "annoying." Many participants said,

- "If it's annoying, it will be disconnected."

In particular, drivers wondered whether the system would be alerting them constantly in heavy traffic or road construction. In those situations, drivers are typically at their most stressed and focused state, and the idea of an alert beeping constantly was a concern for them. One driver noted a specific concern about the auditory alerts for the BSW warning:

- "When I'm in heavy [slow moving or stopped] traffic and need to change lanes, I will engage my signal to show my intent to change lanes; it's a way of asking permission for drivers to make room. Would this [blind spot warning] alert be going off the entire time?"

Some participants were concerned whether the alert sounds would be consistent, or would vary by manufacturer. They expressed anxiety over the possibility they would have to learn new sounds whenever they changed vehicles.

Another common area of caution was an apprehension over whether drivers would become overly reliant on the system. This was especially a concern among the older, more experienced drivers. Many of them felt that younger or novice drivers might rely on the warnings to prevent accidents, instead of developing the skills necessary to prevent accidents through vigilant defensive driving behavior. One driver noted:

- "Overdependence [on a system like this] will cause crashes… When [an alert] doesn't go off, and an accident occurs, who gets blamed? It becomes a liability issue."

More than one driver noted that the IMA application must work differently for a commercial vehicle than for a light vehicle. A senior driver, who was not selected for the interview, wanted to stay anyway to point out the special needs of a double trailer. It will take many seconds to accelerate and cross a multi-lane highway. Another asked,

- "How does it handle busy 6-8 lane intersections?"

Drivers also had suggestions for making the sounds more useful and not simply "beeps."

In general, participants expect that the sensitivity of the system will be adjustable. One representative quote for this suggestion was,

- "Want different sensitivity for city, rural, fog, ice"

Recommendations from the participants can be used as the basis for further development of connected commercial vehicle safety applications.

Procedure and results of the Driver Acceptance Clinics are detailed in a separate report [8]. The objective and subjective data was transmitted to the Volpe National Transportation Systems Center for independent evaluation [10].

Performance Tests

The Performance Tests were intended to evaluate quality of the GPS reception and DSRC communication in a variety of road conditions. Data were collected when the red and white tractors were driven from Ohio to California for the August Driver Clinic. The route included a variety of conditions—urban and rural, two lane to multi-lane, tunnels and bridges, plains and mountains. Data were recorded on the DAS on both tractors in the normal course of driving the trucks, without any intervention required of the drivers. The displays of the applications were disabled during the trips.

The correlation of the data between the two tractors showed excellent performance where DAS records were available. No evidence was found that DSRC performance depended on roadway features or geography. However, gaps in data collected by the DAS prevented evaluating the performance over the entire trip.

The DAS on each tractor recorded its own position from GPS signals independently from the WSU. Each tractor was also recording BSMs from the other tractor, and the range to the other tractor that it calculated from the BSM. Thus, at each moment in time there are three measurements of the range between the two tractors: the range to the red tractor calculated by the white tractor at that moment, the range to white tractor calculated by the red tractor at that moment, and the distance between the two calculated after the trip from DAS GPS data. If all components were functioning properly, those three values would be close. The clocks in the separate tractors were not precisely synchronized, so records were adjusted slightly.

Figure 3-2 is an example of data collected near Laramie, Wyoming, on a mountainous Interstate. The range to the red tractor calculated by the white tractor is represented by the black line, and the range to the white tractor calculated by the red tractor, by the red line. The two agree well, confirming that all equipment was functioning properly for this segment of over five hours. Note that the tractors were hundreds of meters apart during this time.

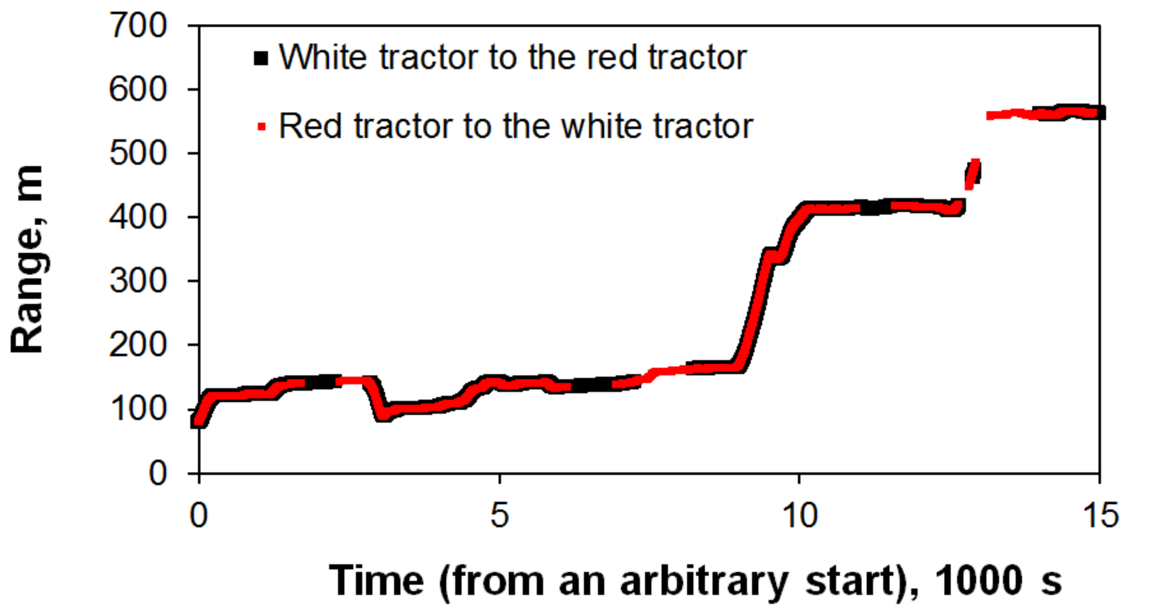

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Figure 3-2. The range to the red tractor calculated by the white tractor, and the range to the white tractor calculated by the red tractor, agree well in this four-hour segment.

Safety Pilot Model Deployment

The Safety Pilot Model Deployment studied connected vehicle technology in naturalistic driving for a year beginning in August 2012 in and around Ann Arbor, Michigan. More than 2800 equipped vehicles were on the road, including the three CCV-IT tractors. The tractors exchanged BSMs with the light vehicles in the study, and V2V safety messages in the tractors were generated. The previous steps of testing included only the four V2V applications; all six safety applications described in Chapter 2 were active during the Model Deployment.

The three tractors were operated by commercial fleets in revenue service for their first few months in the study. However, the tractors were the body style more suitable for long-haul use than in-town pickup and delivery use. Despite efforts by the fleets to maximize the use of the tractors within the range of other Model Deployment vehicles, the number of interactions was less than desired. Therefore, from June to October, 2013, UMTRI drivers operated the three tractors on truck routes in the Model Deployment area. They were driven with trailers on weekdays during morning and afternoon peak traffic hours. As expected, the number of interactions with other V2V-equipped vehicles and the number of safety alerts increased substantially with increased exposure. Table 3-2 shows a summary comparing exposure, V2V interactions, and safety application event count for the fleets and UMTRI drivers. The tractors logged more hours and more miles when they were driven by the fleets, but there were more interactions and more safety warnings when they were driven in town by UMTRI. Trips for maintenance and with known failures are excluded from the table. An "interaction" occurs when the tractor received BSMs from a remote vehicle for more than 0.5 s and a maximum gap of missed messages no more than 5.0 s. V2V safety events exclude the V2I events for the BHI and CSW applications.

Table 3-2. Summary of the exposure, interactions, and safety application events for the CCV-IT vehicles in the Model Deployment.

	Exposure			Interactions		V2V Safety Event	
	Trips	Time	Distance	Event	Time	Inform	Imminent
Operator	count	hours	miles	count	hours	count	count
Fleets	990	2,125	68,778	1716	23	40	7
UMTRI	552	626	12,432	54,133	455	1,736	1,143
Total	**1,542**	**2,751**	**81,210**	**55,849**	**478**	**1.776**	**1,150**

UMTRI

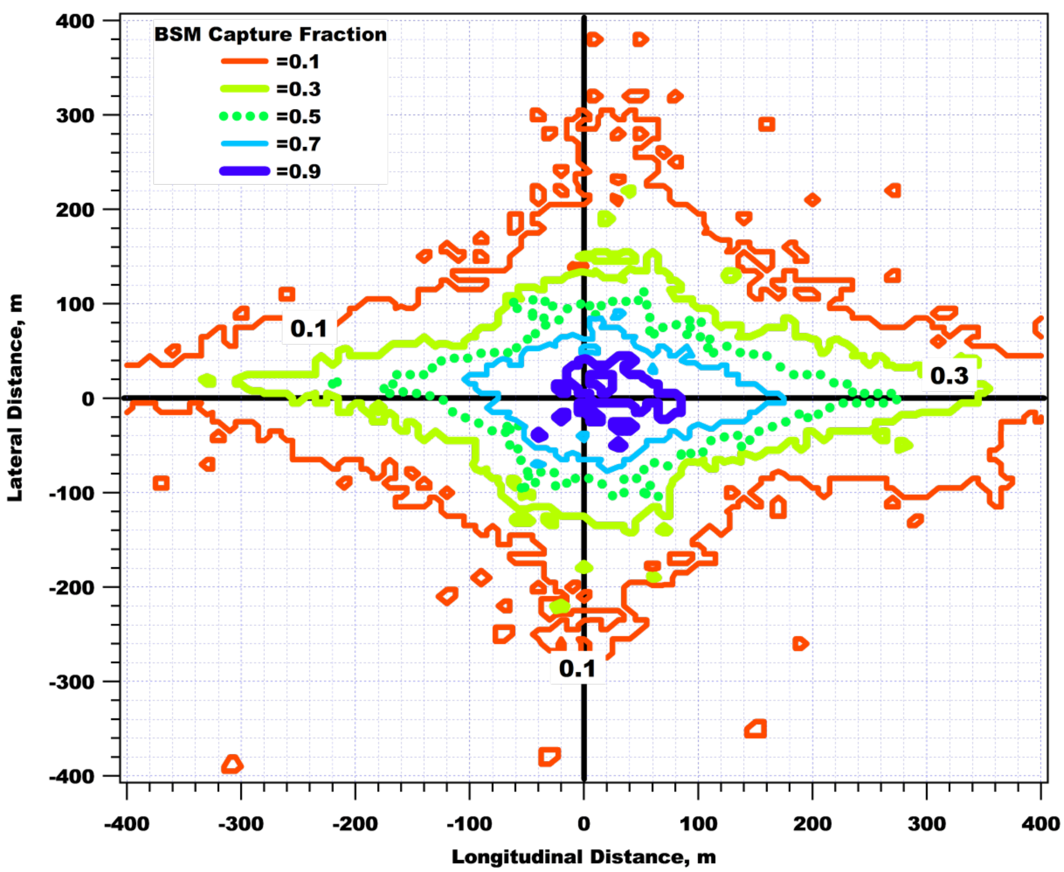
One measure of the performance of the equipment during the Model Deployment is the fraction of BSMs that were captured and recorded. The BSMs from all vehicles in the Model Deployment are in a single database, so it is possible to compute the fraction of BSMs that were broadcast by other vehicles and recorded by the CCV-IT tractors. BSMs are more relevant to the tractor if they come from a vehicle nearby, so the capture fraction was computed as a function of both the remote vehicle's distance from the tractor and its direction from the tractor. The contours in Figure 3-3 show the fraction of BSMs that were captured from vehicles at various distances and directions from the tractors.

The outer red contour shows that the tractors were capturing ten percent of the BSMs from remote vehicles several hundred meters away. The inner dark blue contour shows that more than 90 percent of the BSMs were captured from vehicles up to 80 m in front of the tractor. Other observations from the figure are

- The general shape of the contours shows that reception is better in the fore-aft direction than to the sides of the tractor. The two DSRC antennas were mounted on each side of the tractor (See Figure 2-5) so two antennas have visibility of vehicles ahead and behind the tractor, but only one is available for vehicles to the side. A vehicle more than 40 m to the left or right may be obscured by a building or trees along the road.
- The capture fraction was better than 90 percent for vehicles 20 m behind to 80 m ahead of the CCV-IT and approximately 50 m to each side. This is the important region for the FCW and BSW+LCW safety applications.

- The dotted green contour represents the 50 percent capture fraction. Half of the BSMs broadcast by remote vehicles on the line were recorded by the CCV-IT tractors. The contour line extends from 180 m behind to 280 m ahead of the CCV-IT and approximately 100 m to each side. Reliability to the sides affects the IMA application. For example, a vehicle approaching at 20 m/s (slightly more than 40 mph) is 5 s away at a range of 100 m.
- In the case of EEBL, only a single remote vehicle's hard braking event flags need to reach the CCV-IT. This safety application an effective range of approximately 300 to 400 m or about 0.25 mile.
- This installation and antenna location provide better remote vehicle detection in the forward direction than behind the CCV-IT tractor. This effect is most pronounced at distances up to 200 m. Beyond 200 m the capture fraction is symmetrical both forward and aft.

Complete results of the CCV-IT vehicles in the Model Deployment are in a separate report [6].



UMTRI

Figure 3-3. The fraction of BSMs captured by the CCV-IT tractors depended on the distance and direction to the vehicle sending the BSM. The capture fraction was better than 90 percent for vehicles 20 m behind to 80 m ahead of the CCV-IT and approximately 50 m to each side.

Chapter 4 Outreach

Outreach to industry stakeholders was an important part of promoting this new safety technology. The single most visible event was the demonstration at the ITS World Congress shortly after the project began. Outreach continued through trade shows and posters for drivers.

ITS World Congress

The team was at the 2011 World Congress on Intelligent Transport Systems in Orlando, Florida, for demonstration and program outreach. The team presented and discussed the project with visitors to the Safety Pilot exhibit booth and distributed hundreds of handouts. CCV project personnel from UMTRI, Battelle, MBRDNA, and DENSO were present to answer questions. The project had a booth with posters (Figure 4-1). A the Daimler Safety Truck (Figure 4-2) was equipped with portable V2V technology and was used in in light vehicle crash avoidance demonstrations led by CAMP. Attendees interviewed during the event overwhelmingly responded that it is important that commercial vehicles be included in USDOT research of V2V technology and were pleased to know that commercial vehicles are an integral part of the program. The demonstration is covered in more detail in the summary report on the demonstration [1].

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Figure 4-1. The Safety Pilot tent at the ITS World Congress had a CCV Program outreach posters and program flyers.

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Figure 4-2. The Daimler Safety Truck is shown during a demonstration of the FCW safety application at the ITS World Congress.

Meritor WABCO Booths

Team Member Meritor WABCO included posters and handouts on CCV technology in its booth at four trade shows:

- Mid-America Trucking Show, Louisville, March 2012
- Truck World, Toronto, April 2012
- National Private Truck Council, Cincinnati, April and May 2012
- National Tank Truck Carriers, San Francisco, May 2012

The posters promoted the leadership of USDOT and the capabilities of the safety applications.

Driver Acceptance Clinics

Materials to recruit participants for the Driver Acceptance Clinics served as outreach to the industry as well. Posters describing the technology were put up in places where drivers might see them, such as terminals and truck stops. During the months leading up to the clinics, the team had a web site that described connected vehicle technology. In addition to static copies of the flyers, the site linked to videos on the ITS JPO web site that showed the applications in action. The recruiting process is described more fully in the Driver Clinics report [8].

Industry Conference

Project staff appeared with DOT oversight staff at conferences to present the project's accomplishments. Team members spoke on Connected Commercial Vehicle technology, including interoperability, at the August 2011 V2V safety workshop in Chicago.

Chapter 5 Results

The project completed what it set out to do. Equipment was integrated with three truck tractors. Safety applications that had been developed for light vehicles were modified and proved to work on the commercial vehicles, and new applications were developed. The biggest share of remaining work involves handling the articulation of commercial vehicles and reaching consensus with the light vehicle community on protocols for communicating the position and path of commercial vehicles.

Accomplishments

All of the components of the integrated equipment functioned together, enabling the safety applications to be implemented. The project was well served by the approach of testing the installation of equipment on a tractor and progressing to more elaborate testing conditions.

Successful Installation and Demonstration of V2V Applications

Four safety applications were successfully implemented on working hardware that was integrated with all three tractors. The applications were adapted from light vehicle work and were modified so they were appropriate for the size and characteristics of commercial vehicles. The applications performed through a diverse series of tests. Functional testing with carefully staged scenarios on a test track showed that the applications were working as intended. They issued warnings at the appropriate times and they withheld warnings when vehicles were near but not in hazardous situations. Interoperability with light vehicles was demonstrated during the safety pilot Model Deployment.

The pair of DSRC antennas adequately broadcast and received BSMs over short and long distances. A DVI with visual icons and sounds was developed and implemented in the truck cabs. Engineers from the team upgraded the applications during testing and Model Deployment, refining the software and hardware as new findings occurred.

The system was well liked by the drivers in the clinics. They readily appreciated the benefits of having connected vehicle technology widely deployed. Drivers of all experience levels welcomed the development, but the more seasoned participants cautioned against overreliance on technology.

Two V2I Applications

Two new V2I safety applications were implemented. The Bridge Height Inform (BHI) application is unique to commercial vehicles. It displayed an icon as a tractor approached an overpass on the track used for the Driver Acceptance Clinics at the Transportation Research Center Inc. The application was disabled during the clinics so it would not distract the participants. The curve speed warning application displayed a message if the truck approached at faster than the advisory speed.

The two V2I applications were excluded from the functional testing and the driver clinics. They were active during the Model Deployment. The BHI data was coded directly in the WSU; information for the curves was broadcast by RSE on the approaches to the curves.

Needs for Future Work

While meeting all of the objectives for this initial project, the team discovered and documented a number of needs to be addressed in bringing commercial vehicles into full deployment of connected vehicles. There are technical issues to be addressed, business and operational obstacles to be overcome, and communication between the light vehicle and commercial vehicle communities is essential for ultimate success.

Implications of Vehicle Size

Commercial vehicles are not simply longer versions of light vehicles. There are significant operational differences between the two. Broadcasting a BSM with a longer rectangular size is only a small step toward dealing with the realities of commercial vehicles.

Current light vehicle threat algorithms assume simple box for vehicle. Articulated truck dynamics don't fit well for this model. New threat algorithms are needed for all vehicles to consider articulation of trucks (and light vehicles with trailers). A number of approaches have been considered for dealing with the articulation. Broadcasting independent BSMs for the tractor and trailer would convey the situation but require considerable bandwidth. Alternating BSMs from the tractor and trailer would possibly confuse an algorithm. When an articulated vehicle is on a highway curve, its envelope could be represented by a rectangle of slightly greater width. When a combination vehicle makes a short-radius turn, its trailer moves essentially sideways. Safety applications rely on a path of "breadcrumbs" laid down by vehicles. The path of breadcrumbs from the center of a long, articulated vehicle can be considerably different from the actual path of the truck. Applications in other vehicles need to account for how a truck moves.

Even a consideration as simple as a permitted oversize vehicle needs to be addressed in standards. A light vehicle OBE must not automatically reject as erroneous a BSM claiming to come from a 14-foot-wide vehicle. Handling all of these situations requires cooperation of all stakeholders in both the light vehicle and commercial vehicle communities.

The longer length of commercial vehicles means they require more time to clear an intersection. A loaded truck does not accelerate as fast as a light vehicle, adding more seconds to the clearance time. Taking a loaded double trailer from a stop sign across a four-lane highway is a special skill for truck drivers. This has implications for the IMA application on the commercial vehicle.

Another difficult issue will be that tractors carry different trailers, different loads, and sometimes no trailer at all. This leads to variability in in both dimensions and acceleration performance between trips. The cost of putting a Vehicle Awareness Device on every trailer will not be supported by the economics, and the OBE in the tractor cannot determine the number and length of trailers that are connected. Drivers in the Model Deployment were asked to touch their display to indicate the trailer configuration, but this adds to their workload and is not fully reliable.

The DSRC antennas were measured and were satisfactory for the van trailers and intermodal container in this study. Many different kinds of loads, particularly machinery on flatbeds, may affect the beam pattern.

Business Case

Motor carriers operate with razor-thin profit margins. Costs are scrutinized carefully, and investments must pay for themselves in two years or less. Slow deployment of connected vehicle technology would delay the benefits. Some commercial vehicle OEMs are actively participating in connected vehicle technology, and others are not. The Battelle team found that some are unaware of the potential for regulation change and are not participating in connected vehicle activities.

Integration with the Tractor

Truck Cabs are also busy and tough environments requiring field hardened electronics.

The DVI should emphasize forward visibility without distractions. Light vehicle manufacturers use styling of the instrument panel as part of their distinguishing features. A few participants at the driver clinics volunteered that they regularly drive equipment from different manufacturers. Because response to the warnings has to be immediate and almost reflexive, the appearance and sound of the DVI should be standardized across manufacturers.

OBE must be tightly integrated with the cab for a number of reasons. The number of components and connections can be reduced, minimizing the incremental cost of the technology and improving the reliability. For example, the J1939 communication can be integrated within the WSU, and the GPS receiver can be shared with other services on the truck needing GPS. Integrating the DVI with the instrument panel will make better use of available area. Full integration is also necessary to handle the multitude and complexity of onboard electronic safety and logbook devices.

GPS antennas mounted on the roofs of the cabs generally worked well. However, occasional dropouts need to be understood and addressed.

A better mounting for the DSRC antennas (Figure 2-5) should be found. Antennas in this high, outboard location were damaged by trees in the Model Deployment. A flexible mount was considered toward the end of the project but was rejected because it might not always maintain the antenna in the proper orientation. Integrating the antenna with the mirror body itself would increase its protection because drivers are accustomed to the location of their mirrors. The penalty in range from the slightly lower location should be modest.

New Opportunities

The connected vehicle technology on a commercial vehicle presents new opportunities for improved safety and efficiency.

Simple truck-specific applications might advise a driver of a vehicle carrying hazardous materials of the locations of railroad grade crossings requiring a stop or routes forbidden to hazardous materials. A slightly more sophisticated application would advise truckers on rural highways of significant downgrades so they can enter the grade at the right speed and in the proper gear.

Connected vehicles could be a stepping stone toward more ambitious ends such as platooning.

Chapter 6 Conclusions

The objectives of the project were met. The Request for Proposals that led to this project envisioned that the prototype trucks and applications would be used for four primary purposes:

1. *to support controlled testing of the technology by the National Highway Traffic Safety Administration (NHTSA) so that safety effectiveness can be examined, and benefits (in terms of reduction of crashes) estimated*

   The CCV-IT tractors were made available to NHTSA at the Vehicle Research and Test Center during the summer of 2012. Project staff cooperated with NHTSA staff in testing the vehicles, retrieving data, and applying upgrades when necessary. The CCV-IT technology was demonstrated to NHTSA leadership during a meeting at VRTC in July 2012. At the conclusion of this project, the tractors were returned to VRTC for continued testing.

2. *to support a series of Driver Clinics as a means of evaluating driver acceptance*

   Driver Acceptance Clinics were held in Ohio and California in the summer of 2012. More than 100 professional truck drivers drover though carefully rehearsed scenarios to experience the four safety applications. Questionnaires filled out by the participants and recordings of the interviews were forwarded to the Volpe National Transportation Systems Center for analysis by the independent evaluator. The format of the clinics and the questionnaires were patterned after those in the light vehicle clinics to ease the comparison. Drivers were strongly accepting of the technology and offered valuable suggestions for improvement.

3. *to support operation of the vehicles in a Model Deployment Safety Pilot Test as a means to test overall compatibility and interoperability of connected commercial vehicles with light vehicles*

   The three tractors participated in the Model Deployment for its duration. They exchanged BSMs with light vehicles in the study, and the safety applications on the tractors generated warnings for the driver. The vehicles captured more than 90 percent of the BSMs broadcast by other vehicles within 80 m to the front and 20 m to the sides and rear.

4. *to support ongoing connected vehicle Research and Development activities by related projects*

   The contractor team conducting this project was nearly identical to the team conducting the Connected Commercial Vehicles—Retrofit Safety Device Kit Project. The expected strong synergies were realized. Project team leaders participated in conferences where connected light vehicle technology was presented, for joint outreach to the light and commercial vehicle communities.

Chapter 7 References

[1] Bogard, S., and LeBlanc, D. (UMTRI) (January 31, 2014), "Connected Commercial Vehicles—Integrated Truck Project: Summary Report on Demonstration and Program Outreach at the 18th World Congress on Intelligent Transport Systems." (Report from Battelle to ITS JPO) Battelle document 10003838-503. Contract No. DTFH61-06-D0007/ORDER T11004/WO BA07-092. Publication Number FHWA-JPO-13-109.

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APPENDIX A. Glossary of Terms and Abbreviations

API	Application Programming Interface
Application	a use of the connected vehicle technology to avoid a certain kind of crash, such as Blind Spot Warning (BSW) or IMA (Intersection Movement Assist)
ASD	Aftermarket Safety Device. Not as well integrated with a vehicle as an OBE, but with greater capability than a Vehicle Awareness Device.
BSM	Basic Safety Message. The package of information about a vehicle's position and status that is broadcast to surrounding vehicles by the OBE, ASD, or Vehicle Awareness Device.
BSW + LCW	Blind Spot Warning, Lane Change Warning. A safety application.
CAMP	Crash Avoidance Metrics Partnership. Originally was GM and Ford; now includes Mercedes-Benz, Toyota, Honda, Volkswagen, Nissan and Hyundai-Kia.
CAN	Controller Area Network. Just about all cars and trucks have one nowadays. Lots of parts of the vehicle broadcast their status and receive their instructions from the bus.
CCV	Connected Commercial Vehicles
CDL	Commercial Driver's License
CSW	Curve Speed Warning. An application developed by MBRDNA for commercial vehicles.
CVSCA	Commercial Vehicle Safety Communications Application
DAC	Driver Acceptance Clinic
DAS	Data Acquisition System. Records data for the engineers to examine after the experiment.
GRD	Geometric Road Description
DGPS	Differential Global Positioning System (GPS)
DSRC	Dedicated Short-Range Communication. Think of it as Wi-Fi for the road.
DTNA	Daimler Trucks North America
DVI	Driver-Vehicle Interface. A lighted symbol on the dash, possibly a beep, and maybe a seat vibration
EEBL	Emergency Electronic Brake Light. A safety application.
FCW	Forward Collision Warning. A safety application
FHWA	Federal Highway Administration (part of USDOT)
HIA	"Here I Am." Old name for a Vehicle Awareness Device (which see)

HV	Host Vehicle. The vehicle in which the safety application resides.
IMA	Intersection Movement Assist. A safety application.
ICF	Informed Consent Form
IDI	In-Depth Interview
IRB	Institutional Review Board
ITS JPO	Intelligent Transportation Systems Joint Program Office (part of USDOT)
LTAP / OD	Left Turn Across Path / Opposite Direction.
MBRDNA	Mercedes-Benz Research & Development North America, Inc.
MD	Model Deployment. A parallel but separate project
MITRP	Michigan Technical Research Park
NHTSA	National Highway Traffic Safety Administration (part of USDOT)
NMEA	National Marine Electronics Association
OBE	On-Board Equipment. A device on the vehicle that supports the connectivity
OEM	Original Equipment Manufacturer. Usually this term refers to one of the car manufacturers, but it could be a manufacturer of other things.
OTA	Over-the-Air
RITA	Research and Innovative Technology Administration (part of USDOT)
RSD	Retrofit Safety Device. A device with functionality similar to an OBE that is installed in a vehicle as an aftermarket retrofit. May have slightly less integration than an OBE but is better integrated with the vehicle and has more capability than a Vehicle Awareness Device.
RSE	Road Side Equipment. A device on the stationary infrastructure for connectivity
RV	Remove Vehicle. A vehicle in a scenario other than the HV.
Scenario	An arrangement of vehicles and a plan for their motion intended to demonstrate an application.
SP	Safety Pilot. A parallel but separate project
TIM	Traveler Information Message
TRC Inc.	Transportation Research Center Inc.
UDP	User Datagram Protocol
UMTRI	University of Michigan Transportation Research Institute
USDOT	United States Department of Transportation

Vehicle Awareness Device	(not to be shortened) A device in a vehicle that broadcasts announcing its position to neighboring vehicles. The BSM from a Vehicle Awareness Device contains only location information, no information about the vehicle condition. An OBE does include vehicle status in the BSM.
VRTC	Vehicle Research and Test Center. A laboratory of NHTSA on the grounds of TRC Inc.
VSC-A	Vehicle Safety Communications – Applications
VSC3	Vehicle Safety Communications 3 (Consortium)
V2V	Vehicle-to-vehicle (communication)
V2I	Vehicle-to-infrastructure (communication)
WSU	Wireless Safety Unit

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