Transit Safety Retrofit Package Development

Final Report

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FHWA-JPO-14-142

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16. Abstract

This report provides a summary of the Transit Safety Retrofit Package (TRP) Development project and its results. The report documents results of each project phase, and provides recommended next steps as well as a vision for a next generation TRP.

The objectives of this project included developing, testing, installing, deploying, and maintaining TRPs on three University of Michigan transit buses, including installation of three Basic Safety Applications – Emergency Electronic Brake Lights (EEBL), Forward Collision Warning (FCW), and Curve Speed Warning (CSW), and development of two new Transit-Specific Safety Applications – Pedestrian in Signalized Crosswalk Warning (PCW) and Vehicle Turning Right in Front of Bus Warning (VTRW); participating in the USDOT's Safety Pilot Model Deployment; and collecting and providing data from the TRP-equipped buses to the Volpe Center for an independent evaluation of results. Within the Model Deployment Connected Vehicle (CV) architecture, TRP employed Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) technologies based on Dedicated Short-Range Communication (DSRC), to ultimately determine if these technologies could be combined with the on-board transit safety applications to provide real-time alerting to the transit driver.

17. Key Words	18. Distribution Statement
Transit Safety Retrofit Package (TRP), Safety Pilot Model Deployment, Connected Vehicle (CV), Dedicated Short-Range Communication (DSRC), Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Transit Safety Applications, Pedestrian in Signalized Crosswalk Warning (PCW), Vehicle Turning Right in Front of Bus Warning (VTRW), , Forward Collision Warning (FCW), Curve Speed Warning (CSW), Emergency Electronic Brake Lights (EEBL)	

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Executive Summary

This report describes how a team led by Battelle, on behalf of the United States Department of Transportation (USDOT) Intelligent Transportation Systems Joint Program Office (ITS JPO), Federal Highway Administration (FHWA), and Federal Transit Administration (FTA), deployed five collision avoidance applications on University of Michigan transit buses, including two new transit applications—one for pedestrian crosswalks and one for vehicles turning in front of transit buses at stops—identified as high-priority concerns by transit agencies. This deployment was part of the USDOT's Safety Pilot Model Deployment—a large-scale field demonstration of the potential benefits of 5.9GHz Dedicated Short-Range Communications (DSRC) wireless technology that is supporting related decisions by the National Highway Traffic Safety Administration (NHTSA).

The specific objectives of the Transit Safety Retrofit Package (TRP) project were to design and develop Transit-Specific Safety Applications for transit vehicles that can communicate using Vehicle-to-Vehicle (V2V) as well as Vehicle-to-Infrastructure (V2I) Connected Vehicle (CV) technologies for enhanced transit vehicle and pedestrian safety. Ultimately, it is of interest to determine if DSRC technologies can be combined with on-board safety applications to provide bus drivers real-time alerting of potential and imminent crashes.

To achieve the objectives of the study, the TRP project included developing, testing, installing, and maintaining retrofit packages on three transit buses drawn from the University of Michigan transit fleets, including installation of three Basic Safety Applications – Emergency Electronic Brake Lights (EEBL), Forward Collision Warning (FCW), and Curve Speed Warning (CSW), and development of two new Transit-Specific Safety Applications – Pedestrian in Signalized Crosswalk Warning (PCW) and Vehicle Turning Right in Front of Bus Warning (VTRW); and collecting and providing data from the equipped buses to Volpe, The National Transportation Systems Center for independent evaluation. A description of the five safety applications is presented in Chapter 1.

The TRP system was originally deployed onto the three University of Michigan transit vehicles with a full complement of TRP hardware and software on February 1, 2013. The system was used typically 12 hours per day for an 8-month deployment period. Battelle collected and analyzed data from the deployment, developed limited system refinements based on lessons learned, and redeployed the revised system for 4 weeks during February and March 2014. Data from the redeployment was subsequently collected and analyzed. During the original 8-month deployment, the vehicles experienced 1,720 informational/cautionary (yellow) events, and 1,995 warning (red) events, while during the 4-week redeployment they experienced 262 informational (yellow) events, and 294 warning (red) events.

Battelle analyzed the PCW and VTRW event data as compared to "ground truth" (objective data recorded by a data acquisition system for comparison), to assess the performance of the applications and determine lessons learned. This analysis was performed separately for the original and redeployment periods using the same methodology. As a result of the original deployment analysis, Battelle developed limited near-term system revisions for the redeployment, and provided longer term recommendations for future systems.

The major conclusions and lessons learned from this project include:

- The TRP on-bus software was effective at providing alerts to transit drivers.
- The transit drivers expressed acceptance of the TRP concept.
- There was a high rate of false alerts for the PCW application due primarily to a combination of Global Positioning System (GPS) limitations and pedestrian detector limitations.
- There was a high rate of false alerts for the VTRW application due to GPS limitations.
- Wide Area Augmentation (WAAS)-enabled GPS accuracy is insufficient for the PCW and VTRW applications. Typical lane width is 3.35 meters, thus accuracy within 1.675 meters is required, which cannot reliably be achieved with WAAS-enabled GPS. A more precise technology, such as Differential GPS, should be employed to achieve expected performance levels.
- The Doppler microwave-based crosswalk detectors are insufficient for the PCW application. They cannot adequately discern between pedestrians and slow moving vehicles in the crosswalks. A more discerning technology, such as high-speed imaging, should be employed to achieve expected performance levels.
- DSRC radio technology performed well – there were no TRP problems traced to DSRC radio communications.
- The short-term system revisions yielded expected performance improvements.

Taking a first step in applying the findings of this project, Battelle's vision of a next generation TRP is the subject of the final chapter of this report.

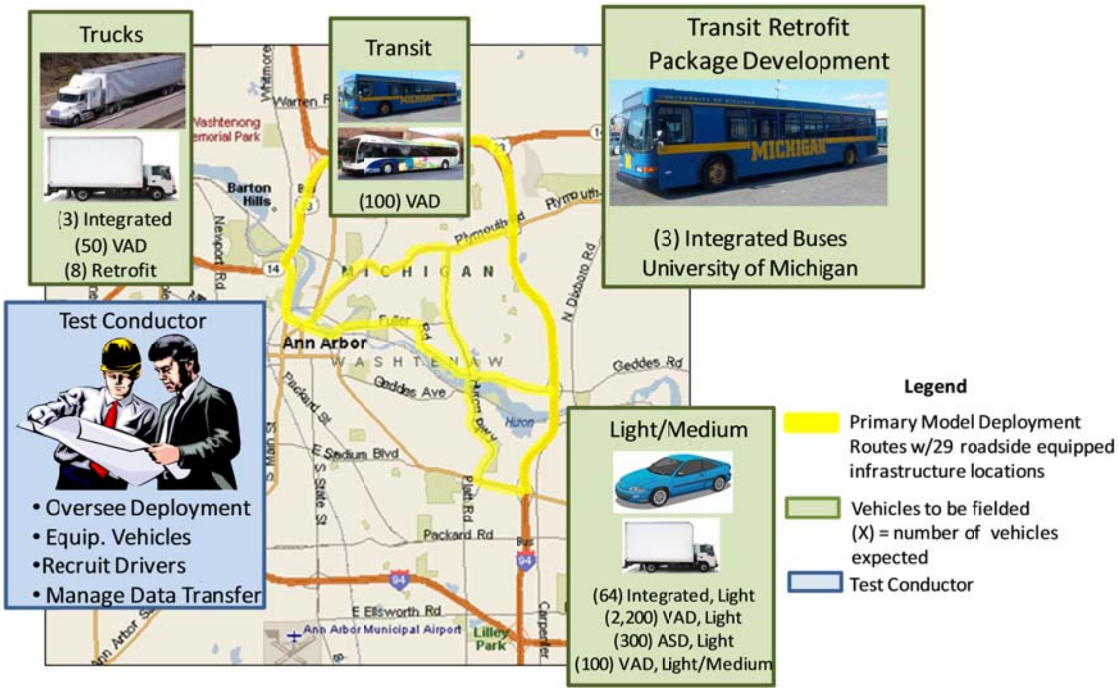
Chapter 1 Scope / Overview

Project Overview

The concept of Connected Vehicles was developed from previous intelligent highway vehicle programs including the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the Transportation Equity Act for the 21st Century (TEA-21) of 1997, and finally the Intelligent Vehicle Initiative (IVI) that was created through TEA-21. Connected Vehicle technologies and applications seek to improve traffic safety and mobility while reducing transportation environmental impacts and enhancing commerce in the areas in which they will be implemented. In broad terms, the Connected Vehicle program envisions a communications infrastructure that includes elements of vehicle-based communication units and other on-board equipment (OBE), infrastructure-based communication units, or roadside units (RSUs), and other roadside equipment, and the centralized network that manages the exchange of data. The various OBE will be able to communicate from vehicle to vehicle and to the RSUs using various wireless communications, potentially including Dedicated Short-Range Communication.

The Safety Pilot Model Deployment, located in Ann Arbor, Michigan, was a centerpiece of the United States Department of Transportation (USDOT) Connected Vehicle program. It played a critical role in generating data to support decisions by the National Highway Safety Administration on the future of Connected Vehicle technology development. Key data included the performance of the various technologies, including DSRC and safety applications, driver adaptations, and the overall crash prevention potential. The TRP project was an important part of the Connected Vehicle program and the Safety Pilot Model Deployment because it provided the only source for retrofitted transit vehicles equipped with safety applications (with respect to DSRC V2V and V2I communications) for participation in the Safety Pilot Model Deployment, a precious, time-constrained opportunity to understand the real-world performance of the transit retrofit packages and safety applications.

Figure 1-1 summarizes key components of the Safety Pilot Model Deployment, which was coordinated by the Test Conductor, the University of Michigan Transportation Research Institute (UMTRI). The Model Deployment included light/medium duty vehicles, trucks, and transit buses. These vehicles were equipped with any of four types of equipment packages: (1) Integrated Safety Systems, (2) Retrofit Safety Devices (RSDs), (3) Aftermarket Safety Devices (ASDs), and (4) Vehicle Awareness Devices (VADs). Integrated packages provide the highest level of functionality. These packages are built into the vehicles during production; connect to the vehicle Controller-Area Network (CAN) buses; broadcast and receive Basic Signal Messages (BSMs) such as vehicle position, speed, heading, and other fundamental information; and process the content of incoming messages to provide drivers warnings through an In-Vehicle Display (IVD). Retrofit equipment, including TRP, differs from integrated packages in that they are not integrated during vehicle manufacture and access only the standard, non-proprietary CAN bus data. ASD equipment provides functionality comparable to the retrofit equipment (IVD, safety applications, warnings/alerts and standard, non-proprietary CAN bus data access) but, unlike the retrofit equipment that is custom-developed for specific vehicle types and not available “off the shelf”, ASD equipment is available on the aftermarket and can be installed in any vehicle. A vehicle awareness device provides the lowest level of functionality, restricted to sending BSMs over DSRC. VADs do not access the CAN bus cannot run applications and do not have an IVD to provide driver alerts. Like the ASD, the vehicle awareness device is an aftermarket device.



Source: Battelle

Figure 1-1. Key Components of the Safety Pilot Model Deployment[1]

The specific objective of the TRP project was to design and develop safety applications for transit buses that can communicate V2V as well as V2I for enhanced transit bus and pedestrian safety. Ultimately, it was of interest to determine if DSRC technologies could be combined with on-board safety applications to provide bus drivers real-time alerting of potential and imminent crashes. The TRP project included developing, testing, installing, deploying, and maintaining retrofit packages on three transit buses drawn from the University of Michigan transit fleet, including installation of three Basic Safety Applications – Emergency Electronic Brake Lights (EEBL), Forward Collision Warning (FCW), and Curve Speed Warning (CSW), and development of two new Transit-Specific Safety Applications (PCW and VTRW); and collecting and providing data from the equipped buses to Volpe, The National Transportation Systems Center for an independent evaluation. The following is a description of the five safety applications included in the TRP:

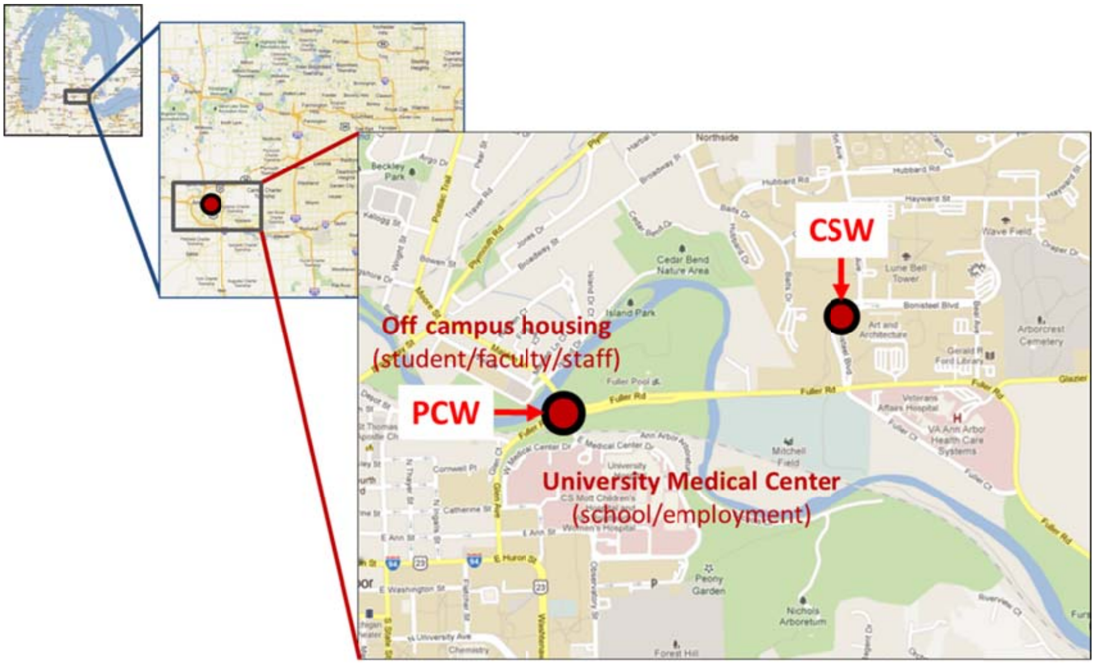
- The FCW application is intended to warn the driver of the host vehicle in case of an impending rear-end collision with an equipped remote vehicle ahead in traffic in the same lane and direction of travel. FCW is intended to help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel.

[1] The numbers shown in the figure for each vehicle type were goals and not necessarily the actual number of vehicles ultimately deployed.

- The EEBL application decodes broadcasts of a self-generated emergency brake event from surrounding equipped remote vehicles. Upon receiving such event information, the EEBL application determines the relevance of the event and provides a warning to the driver if appropriate. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or bad weather conditions (e.g., fog, heavy rain).
- CSW aids drivers in negotiating curves at appropriate speeds. This application uses information communicated from an RSU located ahead of approaching curves. The communicated information from the RSU would include curve location, curve speed limits, curvature, bank, and road surface condition. The device would determine, using other vehicle information, such as speed and acceleration whether the driver needs to be alerted. This application requires the ability to receive a message from the roadside equipment. The CSW is triggered when the bus travels 10 mph over the posted speed limit for the subject curve.
- Pedestrian in Signalized Crosswalk Warning: This V2I application warns a bus driver if pedestrians are in the intended path of the bus when making a right or left turn. This application incorporates two methods of detecting pedestrians—activation of the crosswalk button by a pedestrian and a microwave motion sensor that detects the presence of pedestrians in the crosswalk. The application provides two levels of alerts to the driver—an informational/cautionary indicator if the crosswalk button is activated and an imminent warning if a pedestrian is actually detected in the crosswalk.
- Vehicle Turning Right in Front of Bus Warning: This V2V application warns a bus driver of the presence of vehicles attempting to go around the bus to make a right turn as the bus departs from a bus stop. The application includes two levels of alerts to the driver—an informational/cautionary indicator if an equipped vehicle has moved from behind to beside the bus and an imminent warning if the equipped vehicle shows intent to turn in front of the bus.

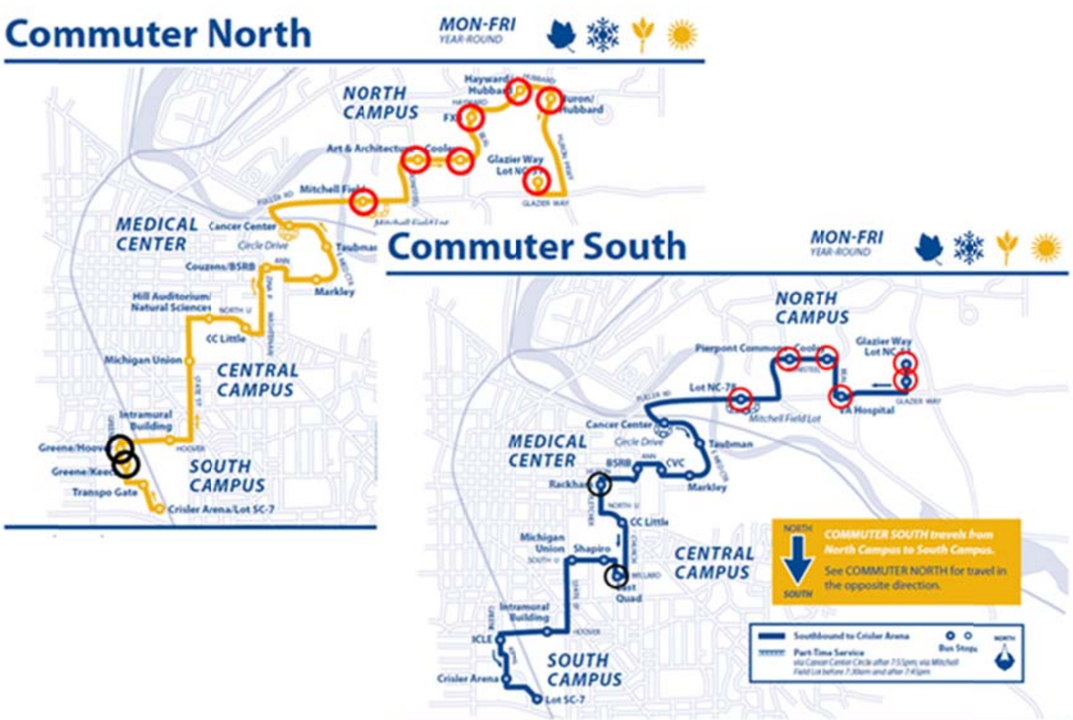
Figure 1-2 shows the locations where the PCW and CSW applications were deployed for TRP, while Figure 1-3 shows the locations where the VTRW application was deployed[2].

[2] There were additional Model Deployment CSW locations not on the TRP-designated bus routes.



Source: Battelle, Google Inc.

Figure 1-2. PCW and CSW Deployment Locations



Source: University of Michigan

Figure 1-3. VTRW Deployment Locations

The PCW location, at the corner of Fuller Road and Medical Center Drive, was selected because the intersection is equipped with SPaT-enabled RSE and has heavy pedestrian traffic. The seventeen VTRW locations were selected as being non-pullout / near-side intersection bus stops on the Commuter North / South routes also including the PCW location. The CSW location on Bonisteel Boulevard (same curve, both directions) was selected as the curve most conducive to excessive speed on the same routes.

The TRP project had four deployment phases as follows:

- Phase 1: FCW, EEBL, and CSW deployed – In August 2012, basic integration on the three UM Transit vehicles was completed, and live testing began in a cloaked mode (alerts were not presented to the driver).
- Phase 2: Data Acquisition System (DAS) deployed – In October 2012, DAS integration on the three UM Transit vehicles was completed, and live testing continued in a cloaked mode.
- Phase 3: PCW and VTRW deployed – In January 2013, PCW and VTRW integration on the three UM Transit vehicles was completed, and eight months of full-up live testing began, uncloaked for data collection and evaluation.
- Phase 4: TRP revisions deployed for Phase 3 lessons learned – In January 2014, TRP revisions were integrated on the three UM Transit vehicles, and in February 2014 one month of full-up live testing began, uncloaked for data collection and evaluation.

Document Overview

The TRP System is a component of the Safety Pilot Model Deployment. The TRP project and this report are restricted in scope to the development, testing, fielding, and results for the TRP System and, while leveraging existing and overarching Connected Vehicle and Safety Pilot Model Deployment design and documentation, this report does not repeat that information. The remainder of this document consists of the following chapters and content:

Chapter 2 (Referenced Documents) lists the external documentation referenced within this document.

Chapter 3 (Summary of Results / Deliverables) provides a summary of the TRP project results and deliverables, organized by tasks:

- TRP Device and Safety Applications
- On-Board Data Acquisition System
- Driver Training
- Model Deployment
- TRP Refinement

Chapter 4 (Vision of Next Generation TRP) provides a vision for a next generation TRP System – a refreshed design concept, taking into account lessons learned and technology advancements.

Appendix A (Terms and Abbreviations) provides definitions for the terms, acronyms and abbreviations used throughout the document.

Chapter 2 Referenced Documents

Institute of Electrical and Electronics Engineers (IEEE)

IEEE 1609.2	Wireless Access in Vehicular Environments (WAVE) – Security Services for Applications and Management Messages
IEEE 802.11p	IEEE Standard for Information technology – Local and metropolitan area networks-- Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments

Society of Automotive Engineers (SAE)

SAE J1939	Serial Control and Communications Heavy Duty Vehicle Network, SAE International
SAE J2735	Dedicated Short-Range Communications (DSRC) Message Set Dictionary, SAE International

DENSO International America

	Aftermarket Safety Device (ASD) User's Guide, Version 1.0

The University of Michigan Transportation Research Institute (UMTRI)

	Transit Safety Retrofit Package (TRP): Data Acquisition System (DAS) Documentation

Battelle

100008379-0001 (FHWA-JPO-14-117)	Transit Safety Retrofit Package Development TRP Concept of Operations
100008379-0002 (FHWA-JPO-14-119)	Transit Safety Retrofit Package Development Architecture and Design Specifications
100008379-0003	Transit Safety Retrofit Package Development TRP Vehicle Install Test Plan
100008379-0004 (FHWA-JPO-14-118)	Transit Safety Retrofit Package Development Applications Requirements Document
100008379-0005	Transit Safety Retrofit Package Development Application Performance and Functional Test Plan Document
100008379-0006	Transit Safety Retrofit Package Development Driver Training Exercises Test Plan

100008379-0007	Transit Safety Retrofit Package Development Driver Training Summary Report
100008379-0014	Transit Safety Retrofit Package Development Phase III Test Report
100008379-0008	Transit Safety Retrofit Package Development Data Dictionary
100008379-0009	Transit Safety Retrofit Package Development Data Delivery – February
100008379-0010	Transit Safety Retrofit Package Development Data Delivery – March
100008379-0011	Transit Safety Retrofit Package Development Data Delivery – April
100008379-0012	Transit Safety Retrofit Package Development Data Delivery – May
100008379-0013	Transit Safety Retrofit Package Development Data Delivery – June
100008379-0017	Transit Safety Retrofit Package Development Data Delivery – July
100008379-0018	Transit Safety Retrofit Package Development Data Delivery – August
100008379-0019	Transit Safety Retrofit Package Development Data Delivery – September
100008379-0024	Transit Safety Retrofit Package Development Data Delivery – February/March 2014 Re-Deployment
100008379-0020	Transit Safety Retrofit Package Development Transit Operator Focus Group Summary Report
100008379-0023	Transit Safety Retrofit Package Development Transit Operator Focus Group II Summary Report
100008379-0022	Transit Safety Retrofit Package Development Proposed TRP and Applications Revisions Report
100008379-0025	Transit Safety Retrofit Package Development Summary of Safety Applications Test Report
60606-018A	Interface Control Document for the Signal Phase and Timing and Related Messages for V-I Applications

Chapter 3 Summary of Results / Deliverables

TRP Device and Safety Applications

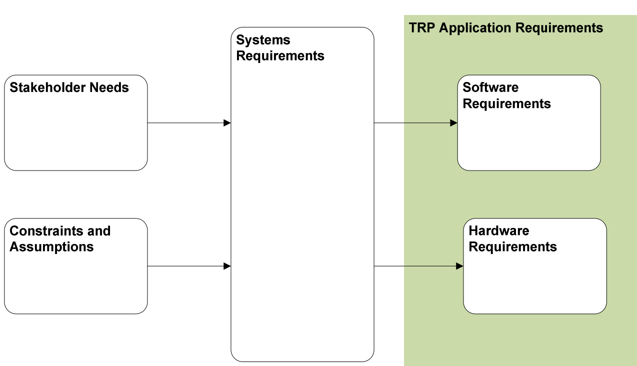
The TRP Device and Safety Applications are documented in the following reports that were generated under this contract:

- Concept of Operations
- Architecture and Design Specification
- Vehicle Install Test Plan
- Applications Requirements Document
- Applications Performance and Functional Test Plan
- Phase III Test Report

This section provides a summary of the TRP Device and Safety Applications development based on these reports. The TRP configuration described here is the final version fielded under this contract, as modified for the TRP redeployment in February/March 2014. The TRP Refinements section of this report covers the specific changes from the original deployment (February through September 2013) to result in the final version described here.

TRP Requirements

Stakeholder Requirements, Constraints, and Assumptions for the TRP System were used to formulate Systems Requirements, and subsequently Hardware and Software Requirements, as depicted in Figure 3-1. System-level requirements are presented after the figure, while the complete set of TRP requirements is contained in the referenced Applications Requirements Document, FHWA-JPO-14-118, available from the National Transportation Library.



Source: Battelle

Figure 3-1. Requirements Process

Stakeholder Requirements

[STK_001] The TRP System shall warn the Transit Vehicle Driver when a pedestrian is in an instrumented crosswalk which intersects the Transit Vehicle's planned left or right turn path at the intersection.

[STK_002] The TRP System shall caution the Transit Vehicle Driver when a pedestrian service call is requested for an instrumented crosswalk which intersects the Transit Vehicle's planned left or right turn path at the intersection.

[STK_003] The TRP System shall warn the Transit Vehicle Driver when a vehicle transmitting Basic Safety Messages is making a right turn in front of a Transit Vehicle leaving a bus stop.

[STK_004] The TRP System shall caution the Transit Vehicle Driver when a vehicle transmitting Basic Safety Messages is located on the left of a Transit Vehicle leaving a bus stop

[STK_005] The TRP System shall host three safety applications: Emergency Electronic Brake Lights, Forward Collision Warning, and Curve Speed Warning as deployed by the Commercial Vehicle Retrofit device.

[STK_006] The TRP System shall have a logging system capable of capturing the changes in state of the hosted applications, and the state of the transit vehicle as it pertains to the inputs to the applications at the time of the transition.

System Constraints and Assumptions

[CONS_ASSUM_001] Intersection will be equipped with an Econolite signal controller.

[CONS_ASSUM_002] The TRP System will transmit compliant Basic Safety Messages.

[CONS_ASSUM_003] The Signal Phase and Timing (SPaT) system will send the status of pedestrian movement in each crosswalk in the SPaT message.

[CONS_ASSUM_004] The TRP equipment shall be installed on three (3) 2011 Gillig Low Floor 40 Transit Vehicles.

[CONS_ASSUM_005] The SPaT system will send the status of each crosswalk button state in the SPaT message.

[CONS_ASSUM_006] (Deleted)

[CONS_ASSUM_007] SPaT Message will include the current or next signal state of all mapped pedestrian lanes.

[CONS_ASSUM_008] SPaT Message will include information to indicate the presence of one or more pedestrians (or the objects) in the crosswalk.

System Requirements

Non Functional Requirements

[SYSREQ_002] The installed TRP equipment shall not obstruct the Transit Vehicle driver’s field of view.

[SYSREQ_003] The TRP shall operate on the voltage supplied by the Transit Vehicle.

[SYSREQ_004] The TRP shall operate in -20◦C to +65◦C Operating Temperature.

[SYSREQ_005] The TRP Pedestrian Detectors shall be installed at two crosswalks and at one intersection.

[SYSREQ_006] The TRP Pedestrian Detectors shall be pole mountable

[SYSREQ_007] The TRP Pedestrian Detectors shall be compatible with voltages provided within Econolite signal control cabinets.

[SYSREQ_008] The TRP Pedestrian Detectors shall operate in -30◦C to +70◦C Operating Temperature.

[SYSREQ_009] The TRP Pedestrian Detectors shall be waterproof.

[SYSREQ_010] The TRP On-vehicle system shall consume less than 150 Watts steady-state.

Curve Speed Warning

[SYSREQ_011] The TRP shall host the Commercial Vehicle CSW application on the Transit Vehicle.

Emergency Electronic Brake Lights

[SYSREQ_012] The TRP shall host the Commercial Vehicle EEBL application on the Transit Vehicle.

Forward Collision Warning

[SYSREQ_013] The TRP shall host the Commercial Vehicle FCW application on the Transit Vehicle.

Transit Vehicle Display

[SYSREQ_014] The TRP shall suppress VTRW aural and visual alerts when the Transit Vehicle is in the park gear.

[SYSREQ_015] The TRP shall provide aural and visual indication when a PCW event occurs.

[SYSREQ_016] The TRP shall provide aural and visual indication when a VTRW event occurs.

[SYSREQ_017] The TRP shall provide aural and visual indication when a CSW event occurs.

[SYSREQ_018] The TRP shall provide aural and visual indication when an EEBL event occurs.

[SYSREQ_019] The TRP shall provide aural and visual indication when a FCW event occurs.

[SYSREQ_020] The TRP latency from safety application event detection to aural and visual display shall be less than 250 milliseconds.

[SYSREQ_021] The TRP System Latency for pedestrian detection shall be no more than 2 sec from detecting pedestrian to warning.

[SYSREQ_022] The TRP System Latency for right turning vehicle shall be no more than 2 sec from receipt of path prediction of right turn conflict data to warning.

[SYSREQ_023] The TRP System will display the alerts regardless of traffic signal status.

[SYSREQ_024] (Deleted)

[SYSREQ_025] The TRP system shall provide a display to the Transit Vehicle Driver that indicates that the application is operational even when there is no caution or warning.

[SYSREQ_026] When the Transit Vehicle is located in a lane in the Geometric Intersection Description (GID) map, the TRP shall present the intersection display including any PCW cautions or warnings.

[SYSREQ_027] When the Transit Vehicle exits the boundary of a GID Map, the TRP shall return to its default operational screen showing the connected status of the TRP System.

Logging

[SYSREQ_028] The system shall log all alerts issued to the driver including the parameters that triggered the alerts.

[SYSREQ_030] The system shall have a mechanism for which the data can be retrieved from the system without any data loss.

[SYSREQ_031] Each TRP System data log shall be associated with the primary keys DeviceID, Time and TripID.

[SYSREQ_032] For logging, the Time primary key shall be implemented as an incremental counter in units of centiseconds (each 10 Hertz [Hz] record increments by 10).

[SYSREQ_033] For logging, the DeviceID primary key shall be implemented as a Unique device Identification (ID) assigned by test conductor. (Note: This ID is made up of the lower 2 bytes of the BSM.)

[SYSREQ_034] For logging, the Trip primary key shall be implemented as an incremental counter based on each ignition cycle.

Pedestrian in Crosswalk Warning

[SYSREQ_036] A PCW caution shall be displayed if the crosswalk button has been activated and that crosswalk intersects the Transit Vehicle's planned left or right turn route at the intersection.

[SYSREQ_037] A PCW warning shall be displayed if a pedestrian has been detected in a crosswalk that intersects the Transit Vehicle's planned left or right turn route at the intersection.

[SYSREQ_038] The PCW warning shall take priority over the PCW caution at the same crosswalk.

[SYSREQ_039] The TRP system shall only display alerts for crosswalks associated with turns at instrumented intersections and on the transit vehicle route.

[SYSREQ_040] The TRP software application shall receive and process MAP and SPAT messages as defined in the SPaT Interface Control Document (ICD) (60606-018A).

[SYSREQ_041] The Pedestrian Detector shall send a pedestrian detected signal when a pedestrian is present in the crosswalk monitored by the pedestrian detector.

Vehicle Turning Right in Front of Bus Warning

[SYSREQ_042] The TRP shall detect whether a vehicle is turning right in front of transit vehicle via the position and heading data received in a basic safety message.

[SYSREQ_043] The VTRW application shall become active (enter a state in which alerts will be generated when conditions warrant) when the transit vehicle stops within a bus stop geographic zone.

[SYSREQ_044] The VTRW application shall remain active until the transit vehicle leaves the bus stop geographic zone.

[SYSREQ_045] The VTRW application shall only alert when the transit vehicle indicates an intended bus stop departure. Bus stop departure intention is indicated when the transit vehicle is in forward gear and the foot brake is disengaged.

[SYSREQ_046] A VTRW caution shall be displayed if a remote vehicle which originates directly behind the transit vehicle at a bus stop begins to pass to the left of the transit vehicle as the transit vehicle is departing a bus stop.

[SYSREQ_047] A VTRW warning shall be displayed if a remote vehicle which originates directly behind the transit vehicle at a bus stop passes to the left of the transit vehicle as the transit vehicle is departing a bus stop and the remote vehicle's position and heading indicates an intent to return to or cross the lane of the transit vehicle.

Interfaces

[SYSREQ_048] The TRP shall receive Signal Phase and Timing for Pedestrian Lanes and Pedestrian presence detection from the SPAT system.

[SYSREQ_052] The TRP shall be able to receive the intersection geometry (MAP) message from the SPAT system.

[SYSREQ_053] The TRP System shall generate and transmit Basic Safety Messages in compliance with SAE standard J2735 version 2009-11.

[SYSREQ_054] The TRP shall be able to interoperate with other model deployment vehicles and Safety Pilot Model Deployment RSU according to IEEE 802.11p and 1609.x standards and the J2735 message standards.

[SYSREQ_055] The TRP shall be able to transmit a SAE J2735 Basic Safety Message (BSM) at least once every 100 milliseconds.

[SYSREQ_056] The TRP shall be able to receive and decode a SAE J2735 BSM.

[SYSREQ_057] The TRP shall have access to the Transit Vehicle's current position.

[SYSREQ_058] The TRP shall have access to the Transit Vehicle's speed.

[SYSREQ_059] The TRP should have access to the Transit Vehicle's gear position.

[SYSREQ_060] The TRP shall have access to the Transit Vehicle's brake status.

[SYSREQ_061] The TRP shall have access to the Transit Vehicle's longitudinal acceleration.

[SYSREQ_062] The TRP shall have access to the Transit Vehicle's yaw rate.

[SYSREQ_063] (Deleted)

[SYSREQ_064] The TRP shall be able to receive and decode a SAE J2735 MAP message.

[SYSREQ_065] The TRP shall be able to receive and decode a SAE J2735 SPAT message.

[SYSREQ_066] The TRP shall be able to receive and decode a SAE J2735 Traveler Information Message.

[SYSREQ_067] The TRP shall have access to Intersection IDs where the Pedestrian Detection equipment exists.

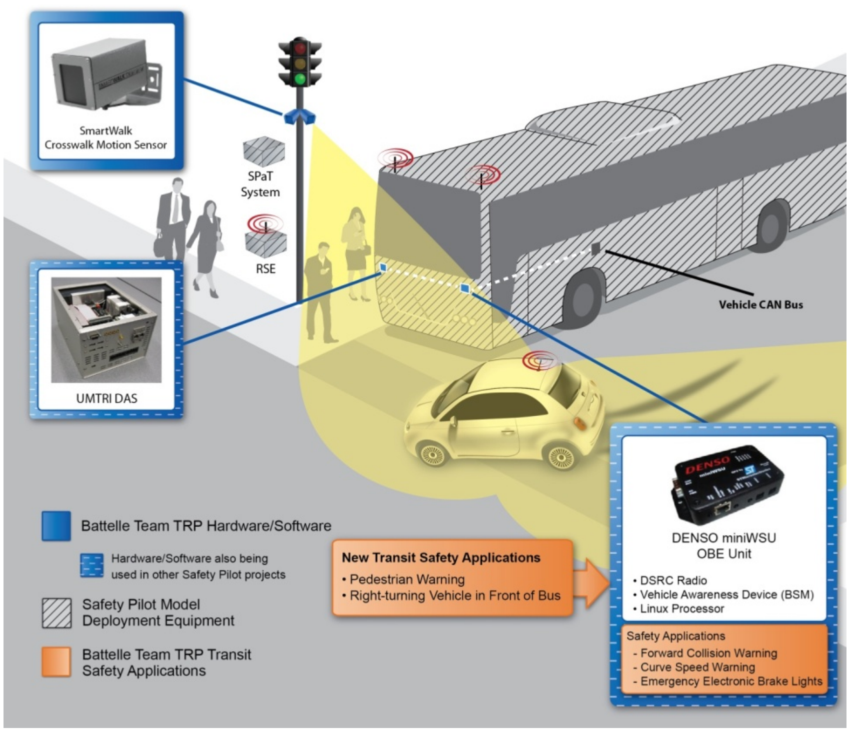
[SYSREQ_068] The TRP shall have the ability to access and store configuration data, including but not limited to, Vehicle Unique ID, Vehicle Length, and Vehicle Type.

TRP CONOPS / Design

Comprehensive TRP System design information is provided in the Architecture and Design Specification, while the Concept of Operations (CONOPS) provides a descriptive overview of the system as well as operational scenarios. These documents, FHWA-JPO-14-119 and FHWA-JPO-14-117, respectively, may be obtained from the National Transportation Library. The Data Acquisition System (DAS), formally outside the boundary of the TRP System, is covered in additional detail in a subsequent section of this report.

System Context

The TRP system, in the context of the Model Deployment infrastructure, is illustrated in Figure 3-2.



Sources: Battelle; UMTRI; http://www.mssedco.com/smartwalk_xp.htm; http://www.densocorp-na.com/technology/vehicle-to-vehicle-vehicle-to-infrastructure-technology.

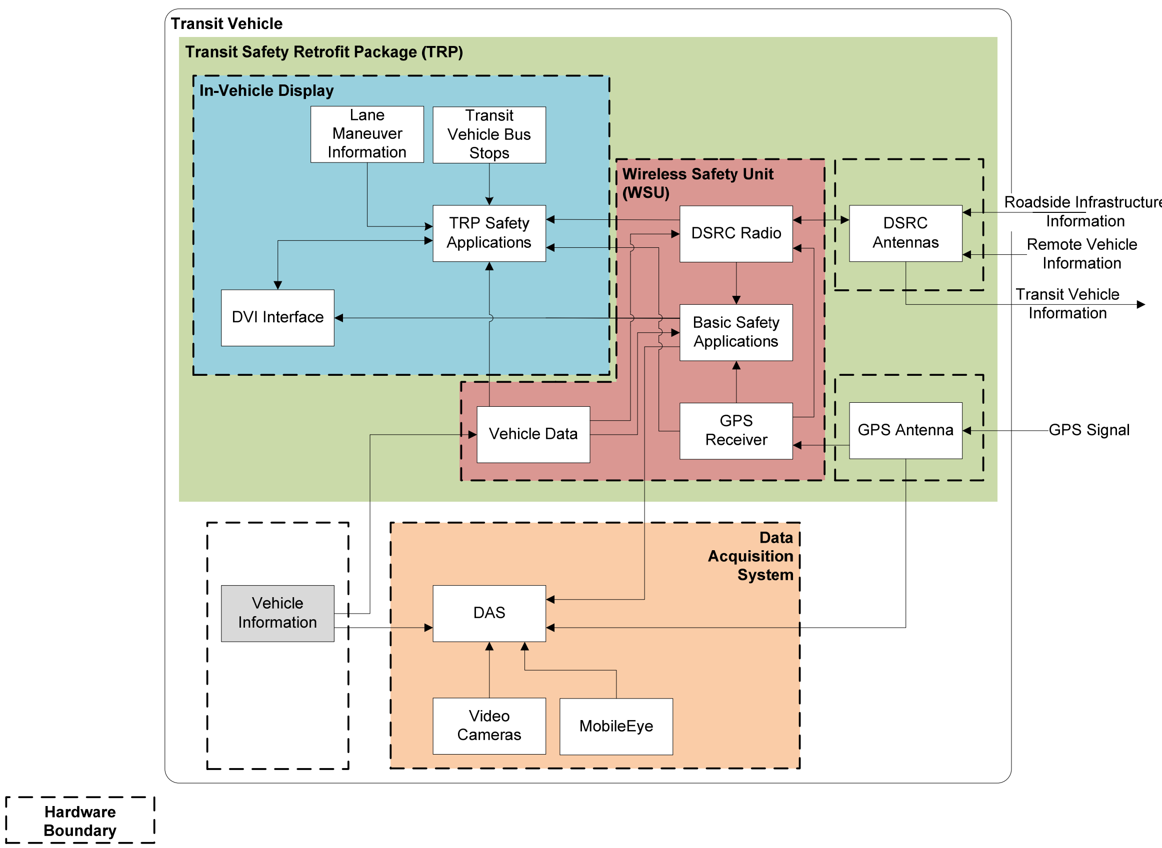
Figure 3-2. Illustration of TRP System in Context of Model Deployment Infrastructure

The TRP System is a standalone set of equipment and software that is installed on a Transit Vehicle. The TRP interoperates with other Safety Pilot Model Deployment vehicles and Roadside Equipment (RSE) according to IEEE 802.11p and 1609.2 standards and the J2735 message standards.

Using J2735 BSMs received from other Safety Pilot Model Deployment vehicles and SPaT, MAP, and TIM (Traveler Information Message) messages received from RSU, along with on-board CAN bus and sensor information, the TRP System provides five safety applications broken down into two categories: 1) Transit-Specific Safety Applications – PCW and VTRW; and 2) Basic Safety Applications – FCW, EEBL, and CSW.

Architecture / Design Overview

A high level architectural view of the TRP System and supporting equipment is shown in Figure 3-3. Roadside Infrastructure Information, Remote Vehicle (RV) Information and GPS Signals are external inputs to the TRP System. The Roadside Infrastructure Information and RV Information inputs are received by a DSRC Radio component and the GPS Signal is received by a GPS Receiver component.



Source: Battelle

Figure 3-3. Architecture and Functional Decomposition

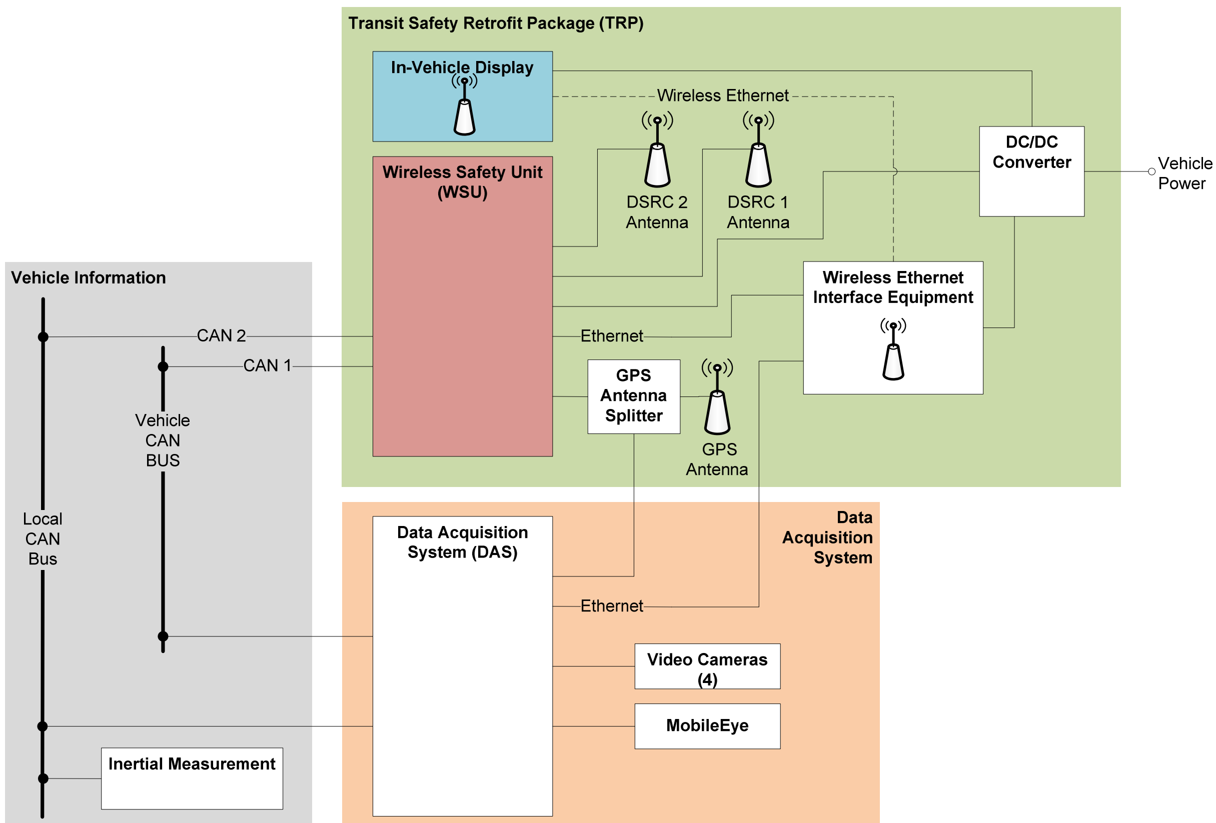
Roadside Infrastructure includes appropriately equipped signalized intersections and curves. Remote Vehicle Information is received from DSRC equipped target/remote vehicles. Transit Vehicle internal inputs to TRP include Vehicle Information (e.g., vehicle speed, vehicle gear position, etc.). TRP transmits the standard BSM.

Components to TRP include DSRC Radio, DSRC Antennas, GPS Receiver, GPS Antenna, Vehicle Data Interface, an IVD, VTRW Bus Stop Location Data [1], PCW Lane Maneuver Information[2], the Transit-Specific Safety Applications, and the Basic Safety Applications.

The DAS, which is not part of TRP, is included as supporting equipment in order to record events and data during the period that the TRP is deployed for the Safety Pilot Model Deployment.

Hardware Overview

A hardware block diagram for the TRP System and supporting equipment is shown in Figure 3-4. This figure identifies the main components and the associated interconnections that are required.



Source: Battelle

Figure 3-4. Hardware Block Diagram

Software Overview

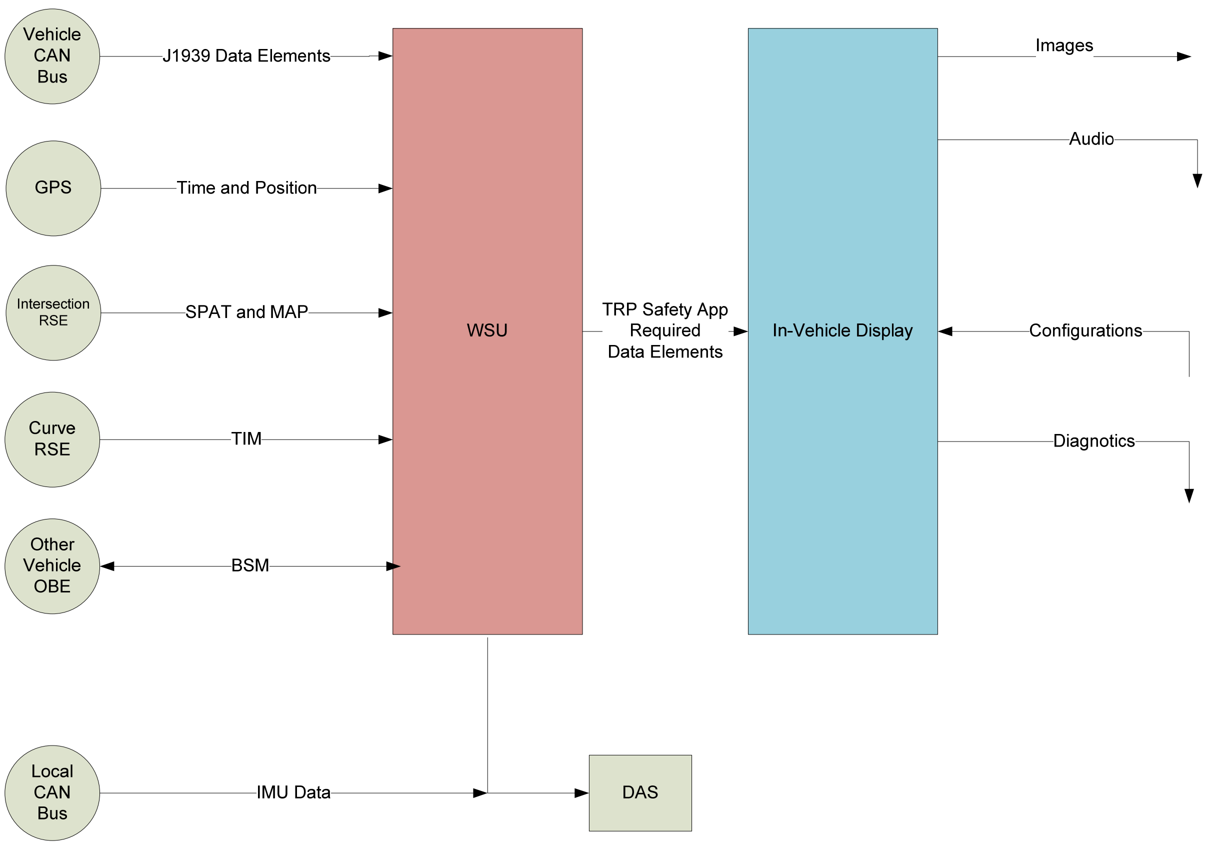
The software for the TRP System addresses three key needs. The first is to integrate three Basic Safety Applications developed for the Connected Commercial Vehicle – Retrofit Safety Device (CCV-

[1] Bus Stop Location Data defines the bus stops of interest for the VTRW application. The TRP application uses this information to determine if the bus is in a VTRW-supported bus stop.

[2] Lane Maneuver Information defines the approach lanes of interest and the associated crosswalk-of-concern for an intersection that is instrumented for PCW. The TRP application uses this information to apply enhanced lane-capture criteria and to determine which monitored crosswalks may be of interest for an approaching transit vehicle.

RSD) project into the TRP – FCW, EEBL, and CSW. The second is the need for two new Transit-Specific Safety Applications – PCW and VTRW. The final need addressed by the software is the provision of operational data on all five safety applications for the Volpe Independent Evaluator (IE).

The design of the TRP software platform is divided into two high level areas. These two areas along with the inputs and outputs to each area can be seen in the software block diagram below in Figure 3-5. The division follows the physical separation of the TRP hardware platform. Software developed for TRP resides both on the Wireless Safety Unit (WSU) as well as the In-Vehicle Display (IVD), a Samsung tablet computer further described in the In-Vehicle Display section below. Additional details about the software developed in each of these areas are described in subsequent sections that describe the IVD and WSU.



Source: Battelle

Figure 3-5. TRP Software Block Diagram

TRP Inputs and Outputs

The data inputs to the TRP system can be divided into four main types. The first is data transmitted via on-board DSRC radio, such as BSM, and data transmitted via RSU, such as SPaT, MAP, and TIM. These messages provide information about the infrastructure or other vehicles to the TRP system.

A second source of information used by the TRP system is data from the Transit Vehicle itself. This information is gathered from the CAN bus to access data such as the vehicle speed and gear position. Needed data is accessed from the vehicle using the J1939 protocol. Because the Transit vehicle itself does not provide all the necessary data over the CAN bus, a secondary input is used to augment the data provided by the vehicle, including the Transit Vehicle's longitudinal and latitudinal acceleration. This data is accessed via a Local CAN bus.

The third source of information utilized is GPS position and time. The need to know where the Transit Vehicle is in relation to other vehicles and roadway structures is necessary to the TRP's ability to accurately alert the driver of any alert conditions.

Finally, the TRP platform utilizes configuration data located on the TRP system itself. For VTRW, this configuration data provides key information regarding the bus stops of interest. This data is used to properly enable the newly developed VTRW safety application at the appropriate locations. For PCW, this data provides lane maneuver information that defines the approach lanes of interest and the associated crosswalk-of-concern. This data is used to apply enhanced lane-capture criteria and to determine which monitored crosswalks may be of interest for an approaching transit vehicle.

As for data outputs of the TRP System, there is only one. As a vehicle participating in the Safety Pilot Model Deployment demonstration, a BSM message is transmitted from the WSU containing the required information about the transit vehicle.

A detailed list of these inputs and outputs is provided in Table 3-1, below.

Table 3-1. TRP Inputs and Outputs

				TRP Applications		Basic Safety Applications						
Inputs	**Source**	**Standard**	**Denso Support Software**	**PCW**	**VTRW**	**CSW**	**EEBL**	**FCW**	**BSM**	**DSRC Channel**	**PSID**	**Notes**
Bootstrap Temporary Unique Name (for Security)		N/A										One time use, Installed by DENSO with bootstrap software, received from SAIC
List of Bus Stops locations where VTR is active	Config File (Database)	N/A			x							
Lane Maneuver Definitions for PCW use	Config File (Database)	N/A		x								
GPS Antenna Offset	Config File (Database)	N/A							X			J2735 200911: Data Element: DF_AntennaOffsetSet
Vehicle Unique ID (for BSM) (stays with the vehicle, not with the device)	Config File (Database)	N/A							X			Value provided by Test Conductor.
Traveler Information Message (Curve info)	Curve RSE	J2735				x				Service Channel	0x8003	PSID from Interoperability Meeting Agenda - 20120312
Transit Vehicle's current GPS position	GPS within WSU	N/A		x	x	x	x	x				
Transit Vehicle's current GPS time	GPS within WSU	N/A		x	x	x	x	x				
Intersection geometry (MAP)	Intersection RSE	SPAT Contract		x						172	0xBFF0	DSRCmsgID = 0x87 for Model Deployment PSID from Interoperability Meeting Agenda - 20120312
Intersection targets (SPAT)	Intersection RSE	SPAT Contract		x						172	0xBFE0	DSRCmsgID = 0x8D for Model Deployment PSID from Interoperability Meeting Agenda - 20120312
Security Credential Management	Intersection RSE	N/A	X	X	X	X	X	X	X	Service Channel	0x23	PSID from Interoperability Meeting Agenda - 20120312
Transit Vehicle's longitudinal acceleration	Local CAN Bus	ISO 15765-4										Logged by DAS
Transit Vehicle's Latitudinal acceleration	Local CAN Bus	ISO 15765-4										Logged by DAS
Transit Vehicle's yaw rate	Local CAN Bus	ISO 15765-4										Logged by DAS
Remote Vehicle's Position	Other Vehicle OBE	J2735			x		x	x		172	0x20	PSID from Interoperability Meeting Agenda - 20120312
Remote Vehicle's Heading	Other Vehicle OBE	J2735			x		x	x				
Remote Vehicle's Length	Other Vehicle OBE	J2735			x							
Transit Vehicle's Position	Vehicle CAN Bus	J1939		x	x	x	x	x	x			
Transit Vehicle's Heading	Vehicle CAN Bus	J1939			x		x	x	x			
Transit Vehicle's speed	Vehicle CAN Bus	J1939			x	x	x	x	x			
Transit Vehicle's gear position (PRNDL)	Vehicle CAN Bus	J1939			x							
Transit Vehicle's brake status	Vehicle CAN Bus	J1939			x							
Transit Vehicle's vehicle length	Vehicle CAN Bus	J1939				x	x	x	x			
Transit Vehicle's vehicle type	Vehicle CAN Bus	J1939				x	x	x				
Outputs	**Source**	**Standard**								**DSRC Channel**		**Notes**
Transit Vehicle BSM data	miniWSU	BSM								172	0x20	PSID from Interoperability Meeting Agenda - 20120312

Source: Battelle

In-Vehicle Display (IVD)

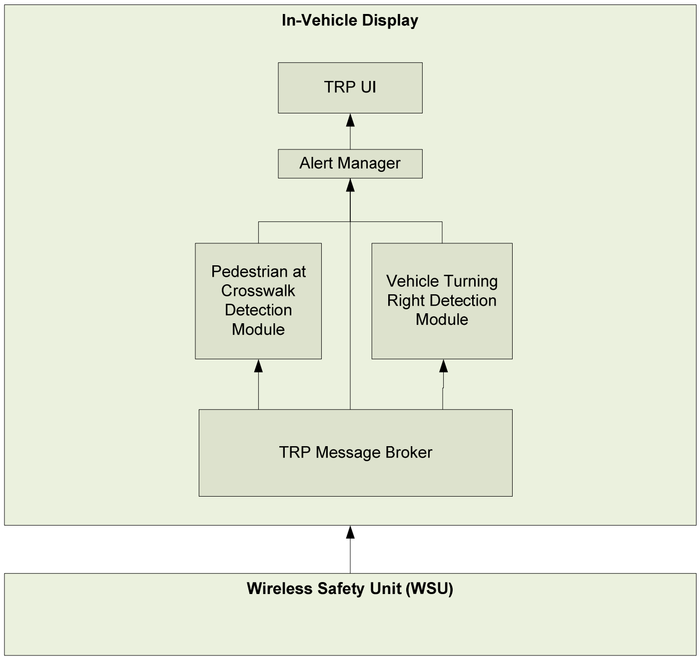
The IVD provides visual and aural alerts to the Transit Vehicle driver for the five safety applications. The IVD performs the computations for the two new safety applications – PCW and VTRW. The IVD is based on a Samsung Galaxy Tab™ computer. This item is a commercial-off-the-shelf (COTS) product, and is equipped with IEEE 802.11 a/b/g/n Wi-Fi® to support communications with the WSU. The mounting of the IVD, shown in Figure 3-6, allows the Transit Vehicle driver to view the display while not obstructing the driver's field of view.

Source: Battelle

Figure 3-6. IVD

Software developed for the IVD is based on the Android™ Operating System (OS). The high level software block diagram is shown in Figure 3-7. A single TRP application was developed for execution on an Android based device. The components of this application include a Message Broker, Vehicle Turning Right Detection Module, Pedestrian at Crosswalk Detection Module, Alert Manager, and the User Interface. The following system activities are addressed by the software on the IVD:

- Message Broker: Receive alerts from CSW, FCW and EEBL applications residing on the WSU and display appropriate alerts to the driver
- PCW Module: Receive and parse SPaT and MAP Message Blob payload data to determine if a PCW alert condition exists and display PCW alerts to the driver
- VTRW Module: Receive and parse Remote Vehicle Position/Heading, and Target Classification data to determine if a VTRW alert condition exists and display VTRW alerts to the driver
- Alert Manager: The Alert Manager performs the task of receiving notification of alerts for the five safety applications and arbitrates the priority for generating the visual and aural alerts.



Source: Battelle

Figure 3-7. IVD High Level Software Block Diagram

TRP Message Broker

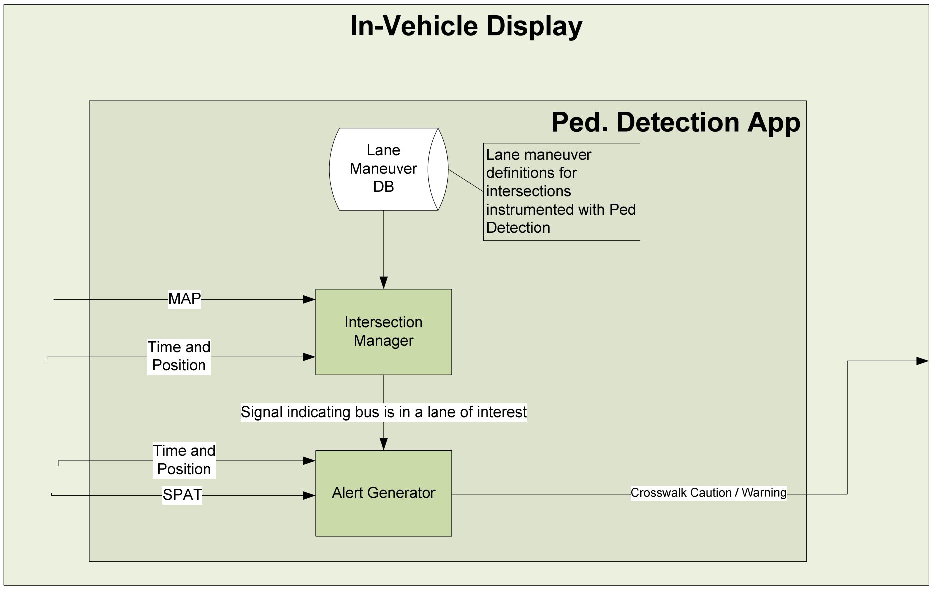
The TRP Message Broker module communicates with the WSU to receive the following information.

- Transit Vehicle's GPS position and time
- Transit Vehicle's speed
- Transit Vehicle's gear position
- Transit Vehicle's foot brake status
- Remote vehicle(s) position and heading
- Remote vehicle(s) target classification
- Intersection SPaT Message Blob payload data
  - Crosswalk phase of particular crosswalk
  - Pedestrian detected in crosswalk and identifier of particular crosswalk
- Intersection MAP message Blob payload
  - Intersection Reference ID
  - Crosswalk lane definitions
- FCW Alert Status
- EEBL Alert Status
- CSW Alert Status

The TRP Message Broker parses and formats the data if needed. The appropriate data is then forwarded to the Pedestrian at Crosswalk Detection Module, Vehicle Turing Right Detection Module, and the Alert Display Module.

Pedestrian at Crosswalk Detection Module

The Pedestrian at Crosswalk Detection Module calculates whether the condition exists that a Pedestrian might be in a crosswalk that the Transit Vehicle is turning toward. A high level block diagram of the Pedestrian at Crosswalk Detection Module is shown in Figure 3-8.



Source: Battelle

Figure 3-8. Pedestrian at Crosswalk Detection High Level Software Block Diagram

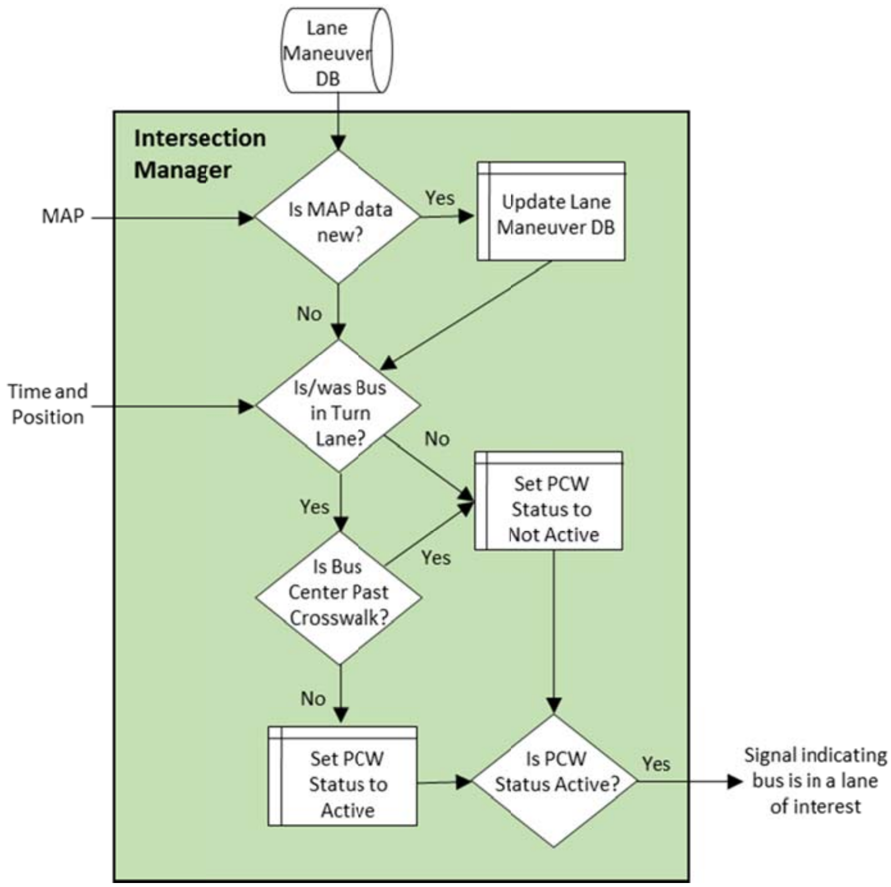
Lane maneuver information for the intersections that are equipped with the properly configured SPaT interface device are stored within a datastore within the module.

The Pedestrian at Crosswalk Detection Module receives the following information from the TRP Message Broker for use in performing the calculations.

- Transit Vehicle's current GPS position and time
- Intersection SPaT Message Blob payload data
  - Crosswalk phase of particular crosswalk
  - Pedestrian detected in crosswalk and identifier of particular crosswalk
- Intersection MAP message data
  - Intersection Reference ID
  - Crosswalk lane definitions

When the Pedestrian at Crosswalk Detection algorithm determines that the conditions exist to alert the Transit Vehicle driver, the alert is sent to the Alert Manager to present the visual and aural alert. The Pedestrian at Crosswalk Detection algorithm supports two levels of alerting – Inform (or Caution) and Warning. An Inform Alert occurs when the Pedestrian Crosswalk Detection algorithm determines that a pedestrian has pressed the Crosswalk button on the intersection that intersects with the Transit Vehicle's projected path during a turning movement as defined in the lane maneuver data. A Warning Alert occurs when the Pedestrian Crosswalk Detection Algorithm determines that a pedestrian has been detected in a crosswalk that intersects with the Transit Vehicle's projected path during a turning movement. The Transit Vehicle's intended path is determined by which lane it is in and how that lane passes through the intersection as defined by the lane maneuver database.

As determined by the Intersection Manager (Figure 3-9), the Pedestrian Detection application only becomes active when the Transit Vehicle is in a designated turn lane based on the Transit Vehicle's GPS position as compared to the Lane Maneuver Database. The application subsequently becomes inactive when the Transit Vehicle turns and the center of the Transit Vehicle enters the crosswalk of interest. Also, the Lane Maneuver Database is updated when new MAP data is received.



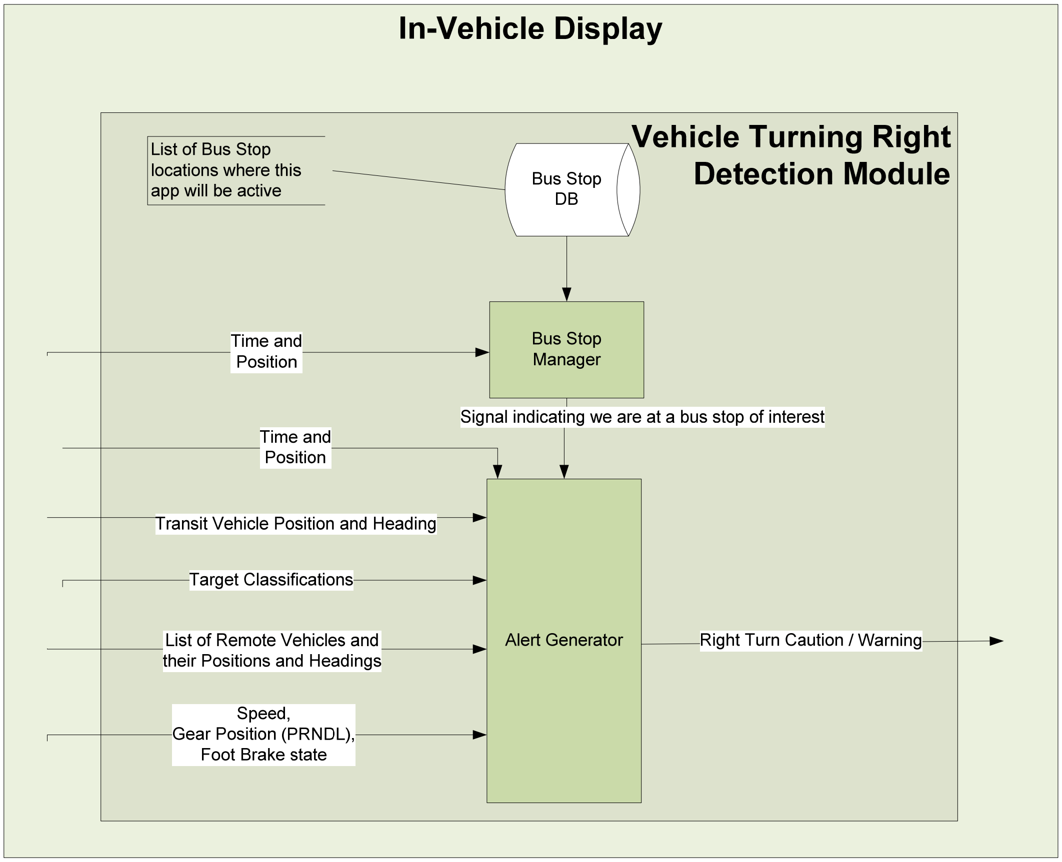
Source: Battelle

Figure 3-9. Pedestrian at Crosswalk Intersection Manager Flowchart

When the Alert Generator receives a signal indicating the bus is in a lane of interest (turn lane), the Alert Generator processes the SPaT data to determine if a pedestrian has either presses the Crosswalk button or has been detected in the crosswalk of interest, in which case an alert is signaled to the Alert Manager.

Vehicle Turning Right Detection Module

The Vehicle Turning Right Detection Module calculates whether the condition exists that a Remote Vehicle might turn right in front of the Transit Vehicle. A high level block diagram of the Vehicle Turning Right Detection Module is shown in Figure 3-10.



Source: Battelle

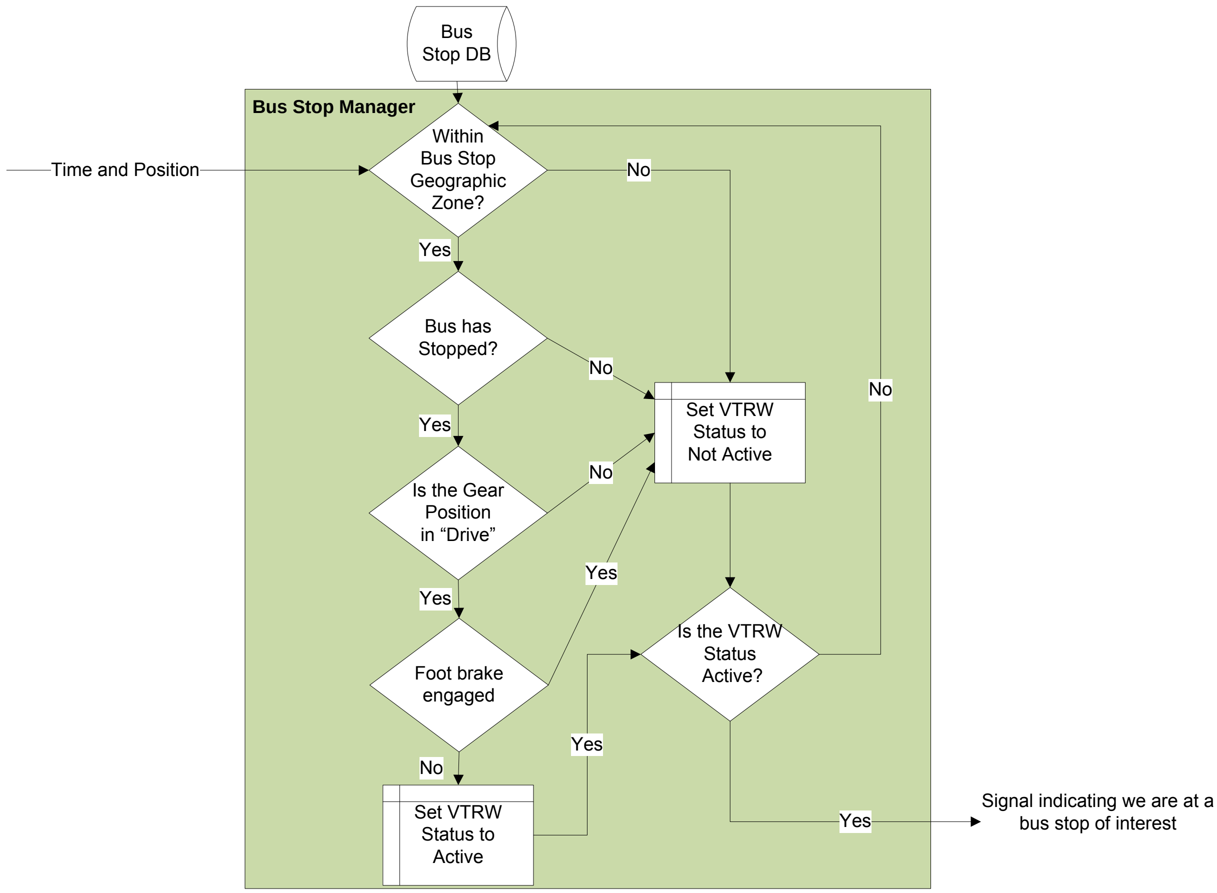
Figure 3-10. Vehicle Turning Right Detection High Level Software Block Diagram

The Bus Stop Manager uses Bus Stop locations for the Transit Vehicle route that are stored within the module for determination that the Transit Vehicle is within proximity of a Bus Stop. The criteria for determining that the Transit Vehicle is within the proximity of the Bus Stop are based on the GPS location of the Transit Vehicle. The current GPS position is compared to the list of Bus Stop location polygons to determine if the Transit Vehicle is inside any of those geographic areas of interest.

The Vehicle Turning Right Alert Generator Module receives the following information from the Message Broker for use in performing the calculations.

- Transit Vehicle's current GPS position and time
- Transit Vehicle's speed
- Transit Vehicle's gear position
- Transit Vehicle's foot brake status
- Transit Vehicle's position and heading
- Remote vehicle(s) position and heading
- Remote vehicle(s) target classification

The Alert Generator calculations are performed against each Remote Vehicle that is included in the list of Remote Vehicles detected by their BSM messages while the Transit Vehicle is within the proximity of a Bus Stop location (calculations are not made when a bus is passing a bus stop and did not stop at the bus stop location). No calculations are performed by the Vehicle Turning Right Detection Module when the Transit Vehicle is not within the proximity of a Bus Stop location on the route. The Vehicle Turning Right Detection module only becomes active once the Transit Vehicle has come to a stop within the Bus Stop location. Figure 3-11 shows a flowchart of the Bus Stop Manager logic to determine when to trigger the Vehicle Turning Right Detection module to become active.



Source: Battelle

Figure 3-11. Vehicle Turning Right Bus Stop Manager Flowchart

The v2v-i application provided as COTS software on the WSU receives the BSMs from any Remote Vehicle within communications range. The BSM messages are processed and made available to other applications by storing the data into Shared Memory. For the Vehicle Turning Right Detection module, of particular interest is Position, Heading, and Target Classification. The Target Classification provides a relative classification of the locations of remote vehicles relative to the host vehicle.

When the Vehicle Turning Right Detection algorithm determines that the conditions exist to alert the Transit Vehicle driver, the alert is sent to the Alert Manager to present the visual and aural alert. The Vehicle Turning Right Detection algorithm supports two levels of alerting – Inform (or Caution) and Warning. An Inform Alert occurs when the Vehicle Turning Right algorithm determines that a Remote Vehicle has traveled from behind the Transit Vehicle and is now to the left of the Transit Vehicle. A Warning Alert occurs when the Vehicle Turning Right algorithm determines that the condition exists that a Remote Vehicle has traveled from behind the Transit Vehicle, then to the left of the Transit

Vehicle, and now is in front and left of the Transit Vehicle as the Transit Vehicle shows intent to depart a Bus Stop. If the Remote Vehicle's position and heading indicates that it will transition into the position ahead of the Transit Vehicle (either resuming in the lane directly in front of the bus or making a right turn immediately in front of the bus), the Warning Alert is signaled.

Alert Manager

The Alert Manager performs the task of receiving notification of alerts for the five safety applications and arbitrates the priority for generating the visual and aural alerts. The alert levels for the Transit-Specific Safety Applications are shown in Table 3-2.

Table 3-2. VTRW and PCW Alert Levels

Application	Inform Alert Criteria	Warning Alert Criteria
Vehicle Turning Right	Remote Vehicle which originated behind the Transit Vehicle is now detected in the adjacent lane to the left of the Transit Vehicle.	Remote Vehicle detected that intends to turn in front of Transit Vehicle. Immediate driver action required.
Pedestrian at Crosswalk	Crosswalk button on crosswalk pressed. Potential for pedestrian to cross roadway at intersection.	Pedestrian detected in crosswalk, driver action required immediately.

Source: Battelle

When the notification is received, a visual indication is depicted and a corresponding aural alert occurs. Aural alerts for the Transit-Specific Safety Applications are described in Table 3-3.

Table 3-3. VTRW and PCW Aural Alerts

Application	Inform Alert Audio	Warning Alert Audio
Vehicle Turning Right	"Right Turn Vehicle Alert"	"Right Turn Vehicle Warning "
Pedestrian at Crosswalk Left	"Pedestrian Alert Left"	"Pedestrian Warning Left"
Pedestrian at Crosswalk Right	"Pedestrian Alert Right"	"Pedestrian Warning Right"

Source: Battelle

The Basic Safety Applications determine whether the conditions exist to generate a FCW, EEBL, or CSW alert. The applications reside on the WSU. The notifications of an alert for the Basic Safety Applications are communicated from the WSU to the IVD. The Message Broker passes this information to the Alert Manager. The Basic Safety Applications Alert Levels are described in Table 3-4, which is a copy of Table 4-1 of the DENSO ASD User's Guide.

Table 3-4. Basic Safety Applications Alert Levels

Application	Inform Alert Criteria	Warning Alert Criteria
FCW	FCW threat detected driver action required.	Imminent FCW threat, driver action required immediately.
EEBL	Remote Vehicle (RV) hard braking detected in adjacent lane.	RV hard braking detected in same lane.
CSW	Host Vehicle (HV) approaching curve and exceeding advisory speed.	HV in curve and exceeding advisory speed.

Source: DENSO

When a Basic Safety Application alert occurs, a visual indication is depicted and a corresponding aural alert occurs. Aural Alerts for the Basic Safety Applications are described in Table 3-5.

Table 3-5. Basic Safety Applications Aural Alerts

Application	Inform Alert Audio	Warning Alert Audio
Forward Collision Warning	"Forward Collision Alert"	"Forward Collision Warning"
Emergency Electronic Brake Light Left	"Braking Ahead Left Alert"	"Braking Ahead Left Warning"
Emergency Electronic Brake Light Right	"Braking Ahead Right Alert"	"Braking Ahead Right Warning"
Emergency Electronic Brake Light Ahead	"Braking Ahead Alert"	"Braking Ahead Warning"
Curve Speed Warning Left	"Curve Speed Alert Left"	"Curve Speed Warning Left"
Curve Speed Warning Right	"Curve Speed Alert Right"	"Curve Speed Warning Right"

Source: Battelle

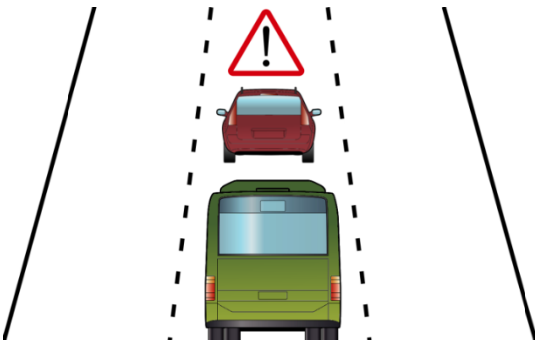
The Transit-Specific Safety Applications are focused on the situation where the Transit Vehicle is stopped, accelerating from a stop, or turning at a signalized intersection; the Transit Vehicle is typically at a lower rate of speed. The Basic Safety Applications are typically geared toward alerting the Transit Vehicle driver when the Transit Vehicle is moving at speed. Therefore, it is unlikely that the Transit-Specific Safety Application alert would occur simultaneously with a Basic Safety Application alert. However, if the condition does arise where there would be a Transit-Specific Safety Application alert and a Basic Safety Application alert at the same time, the Transit-Specific Safety Application alert would take priority over the Basic Safety Application alert.

Contained within the WSU is an alert arbitrator for the Basic Safety Applications which prioritizes the multiple alerts and only generates one alert at a time. As a whole, the TRP alerts are prioritized as follows (1 being the highest priority):

1. PCW warning alert
2. VTRW warning alert
3. PCW caution alert
4. VTRW caution alert
5. FCW warning alert
6. EEBL warning alert
7. FCW caution alert
8. EEBL caution alert
9. CSW warning alert
10. CSW caution alert

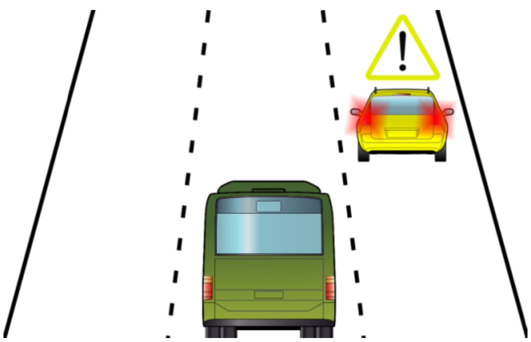
User Interface

The User Interface depicts the appropriate display for the Transit Vehicle driver depending on if an alert is present. The following figures (Figure 3-15 through Figure 3-17) depict a set of sample alert screens that the IVD may depict to the Transit Vehicle driver. Not all permutations of alert types and levels are shown.



Source: Battelle

Figure 3-12. FCW Warning Display Screen



Source: Battelle

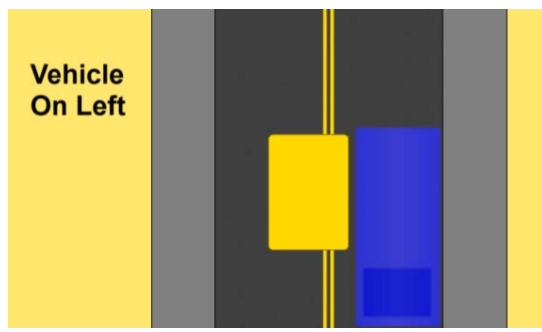
Figure 3-13. EEBL Inform Display Screen

Source: Battelle

Figure 3-14. CSW Inform Display Screen

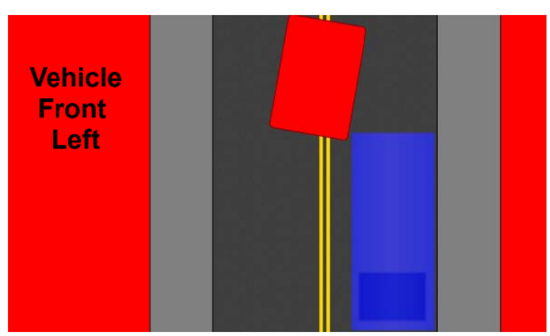
Source: Battelle

Figure 3-15. PCW Warning Display Screen



Source: Battelle

Figure 3-16. VTRW Inform Display Screen

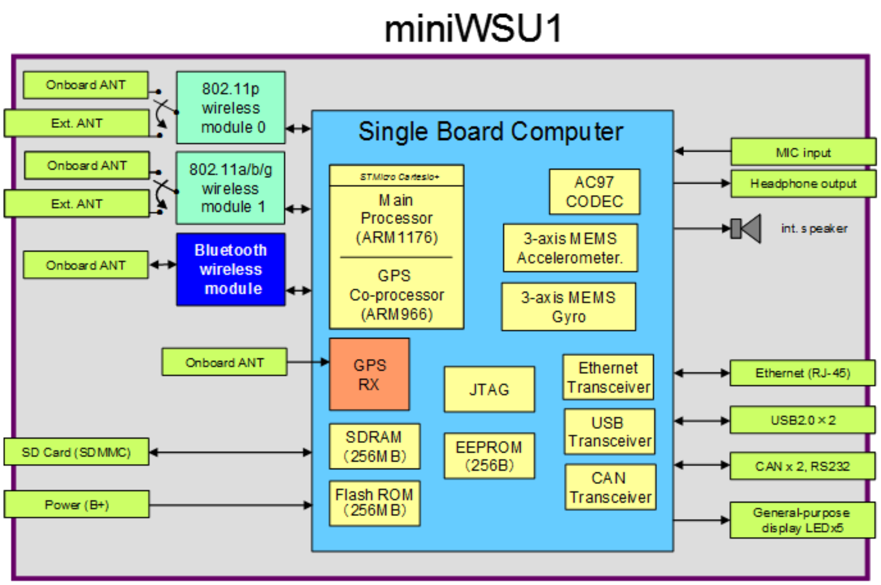


Source: Battelle

Figure 3-17. VTRW Warning Display Screen

Wireless Safety Unit (WSU)

The WSU is a DENSO miniWSU. This unit includes a dual channel DSRC radio, GPS Receiver, and processing capability for the three Basic Safety Applications. This device interfaces to the IVD, DAS, and the DSRC Antennas. This unit is viewed as a COTS item which has software additions included to support the Transit-Specific Safety Applications and the display of alerts. Figure 3-18 provides a schematic of the DENSO miniWSU



Source: DENSO

Figure 3-18. Schematic of the DSRC Radio – DENSO miniWSU

The DENSO miniWSU solution is a custom computing and communications platform specifically designed for the development, implementation, testing, and evaluation of 5.9 GHz DSRC V2X applications. The device incorporates ST Microelectronics Cartesio+ chipset with an ARM11 application central processing unit (CPU), embedded GPS receiver, and Atheros WAVE transceivers to facilitate the development of safety and non-safety ITS applications.

Externally mounted GPS and DSRC radio antennas are used to support receiving GPS Signals and bidirectional communications on the DSRC radio. The TRP has two DSRC Radios built-in to the WSU. Thus, two DSRC Antennas are utilized. DSRC Antenna 1 is a "Whip" style antenna that mounts to the driver side mirror of the transit vehicle (Mobile Mark PN: EC012-5800). DSRC Antenna 2 is a glass mounted antenna that is mounted on the inside windshield of the transit vehicle (Mobile Mark PN: EDN137-1600). The GPS antenna is combined with a cellular antenna required by the DAS (Laird PN: GPST821/18503P).The software configuration uses Linux as a general purpose OS. The DENSO miniWSU is preconfigured with software to support interfacing with the Vehicle CAN bus, the GPS receiver, and managing the DSRC radio. For the TRP Model Deployment, it was decided to use pre-loaded two-year security certificates. Additionally, the three Basic Safety Applications are resident on the miniWSU and preloaded.

The processing of the Radio messages, GPS Position, and Vehicle data result in a common shared memory which applications may use. Shared Memory is a means of performing inter-process communication. Information received and processed by one application can be stored in a common location for easy access and use by other applications running on the same machine.

The WSU receives the following information:

- Transit Vehicle's current GPS position and time
- Transit Vehicle's speed
- Transit Vehicle's gear position
- Transit Vehicle's brake status
- Transit Vehicle's vehicle length
- Transit Vehicle's vehicle type
- Intersection MAP
  - Intersection Reference ID
  - Crosswalk lane definitions
- Intersection SPaT Message Blob payload data
  - Crosswalk phase of particular crosswalk
  - Pedestrian detected in crosswalk and identifier of particular crosswalk
- Basic Safety Messages
  - Remote vehicle(s) path history
  - Remote vehicle(s) position and heading
- Traveler Information Message (TIM) for Curve Speed Warning

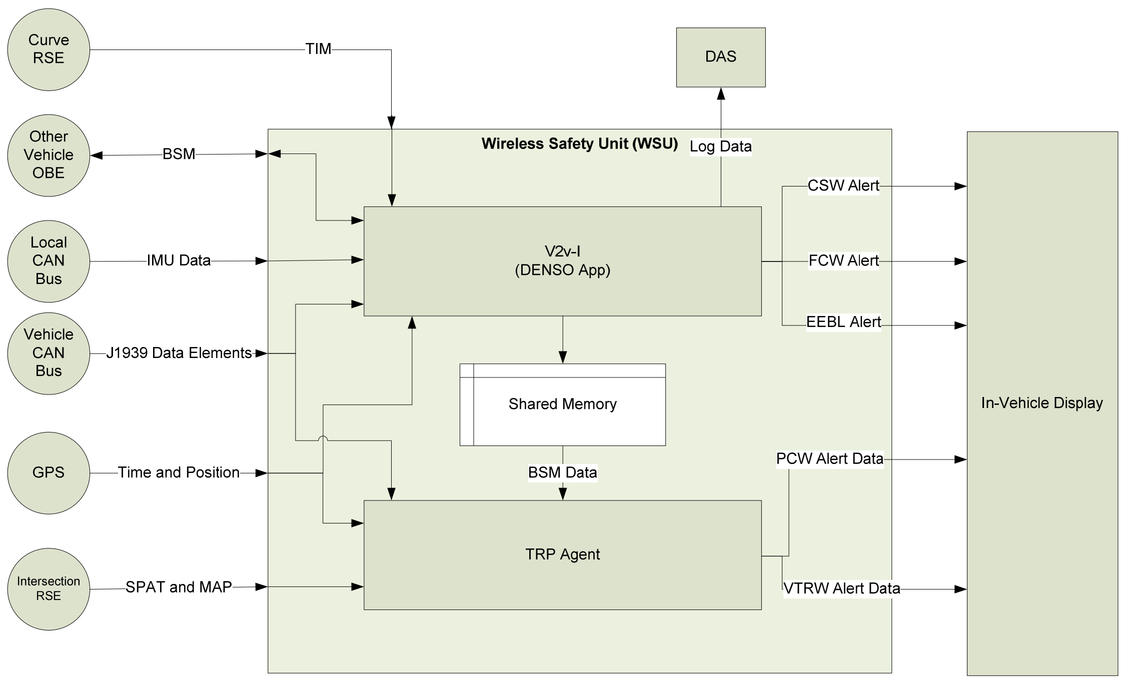
The WSU transmits the following information to the IVD

- Transit Vehicle's GPS position and time
- Transit Vehicle's speed
- Transit Vehicle's gear position
- Transit Vehicle's foot brake status
- Remote vehicle(s) position and heading
- Remote vehicle(s) target classification
- Intersection SPaT Message Blob payload data
  - Crosswalk phase of particular crosswalk
  - Pedestrian detected in crosswalk and identifier of particular crosswalk
- Intersection MAP message Blob payload
  - Intersection Reference ID
  - Crosswalk lane definitions
- FCW Alert Status
- EEBL Alert Status
- CSW Alert Status

The WSU transmits the following information on the DSRC Radio.

- SAE J2735 BSM approximately once every 100 milliseconds.

As illustrated in Figure 3-19, the two main applications running on the WSU are the v2v-i and TRP Agent.



Source: Battelle

Figure 3-19. WSU Software Block Diagram

The v2v-i application provided as COTS software on the WSU receives as inputs DSRC radio messages (including BSMs, SPaT, MAP, and TIM), GPS data, and CAN data. The v2v-I application outputs include alerts for the three Basic Safety Applications, as well as data stored into Shared Memory that is needed by the Transit-Specific Safety Applications on the IVD. For the Turning Right Detection module on the IVD, of particular interest is Position, Heading, and Target Classification. The Target Classification provides a relative classification of the locations of remote vehicles relative to the host vehicle.

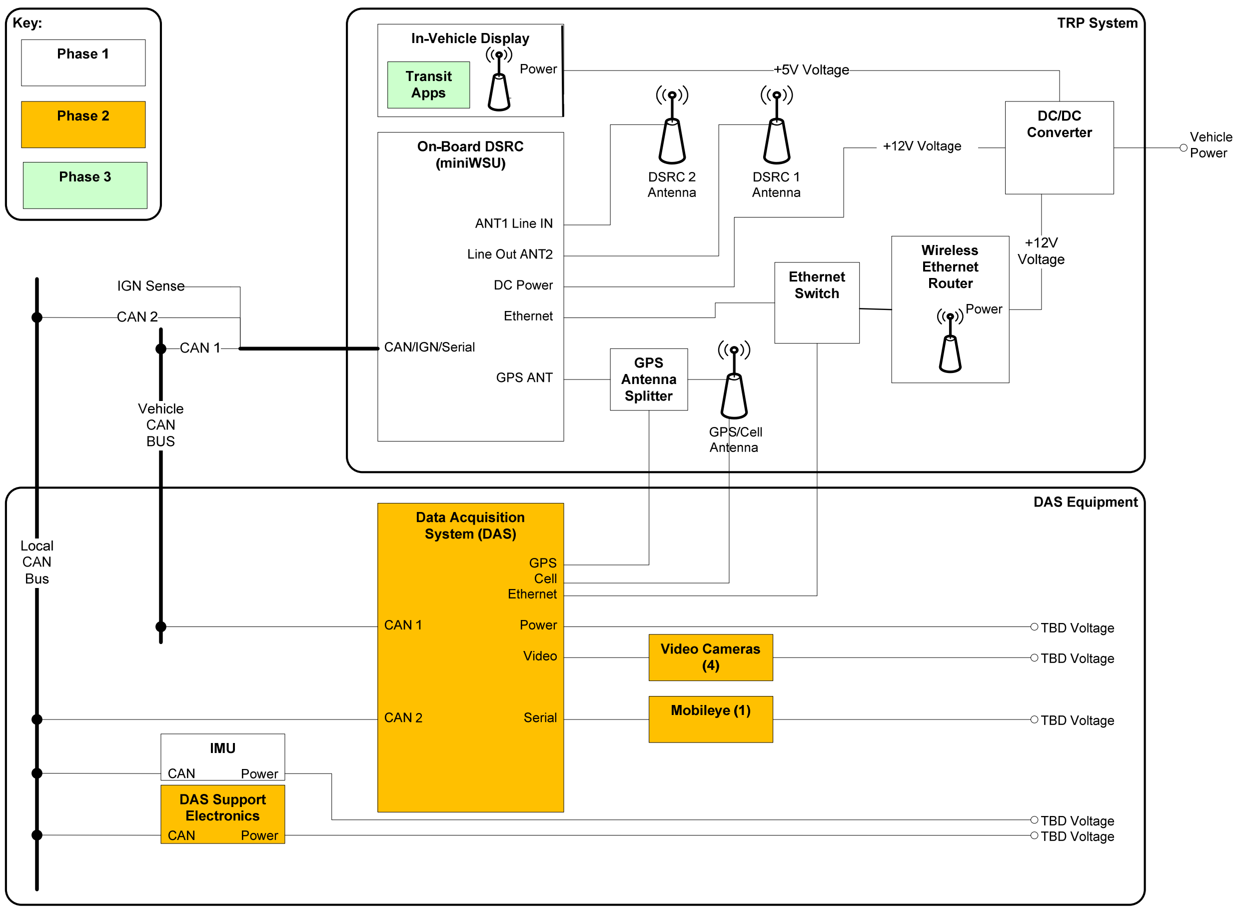
While the majority of the WSU software is COTS from DENSO, a small set of functionality is provided by customized software which is needed to collect and process required data to support the Transit-Specific Safety Applications. The TRP Agent performs the task of acquiring data from the GPS, DSRC radio, Vehicle CAN bus and shared memory and packaging it to be sent to the IVD.

TRP Installation

This section provides a summary of the TRP Installation on the three University of Michigan 2011 Gillig Low Floor 40-foot transit buses that were employed on this project. The Vehicle Install Test Plan provides more comprehensive documentation.

Installation Overview

The TRP equipment was installed in each transit bus as shown in Figure 3-20, TRP Transit Vehicle System Installation Block Diagram. The hardware installation was performed in three phases, as shown in the diagram. Phase 1 installation provided for functionality of the FCW, EEBL, and CSW Basic Safety Applications as well as limited data storage capability. Phase 2 installation was for DAS, covered in the On-board Data Acquisition System section of this report. Phase 3 was the software installation of the PCW and VTRW Transit Applications, using a laptop that had the TRP updated software and Samsung Kies tool to perform the installation on the IVD.



Source: Battelle

Figure 3-20. TRP Transit Vehicle System Installation Block Diagram

The components for the Phase 1 installation included:

- IVD
- On-Board DSRC (miniWSU)
- DSRC Antenna 1
- DSRC Antenna 2
- GPS Antenna Splitter
- GPS/Cell Antenna
- DC/DC Converter
- Wireless Ethernet Router
- Inertial Measurement Unit (IMU)

The components for the Phase 2 installation included:

- Data Acquisition System (DAS)
- Four (4) Video Cameras
- One (1) Mobileye range detector
- DAS Support Electronics

IVD

The IVD (circled) was mounted using a flexible arm mount as shown in Figure 3-21.

Source: Battelle

Figure 3-21. IVD Location

Power to the IVD was routed upward along the central windshield column to an overhead compartment behind the driver's head and behind the vehicle electronics compartment (Figure 3-22) to the DC/DC Converter.

Source: Battelle

Figure 3-22. Overhead Compartment (left), Vehicle Electronics Compartment (right)

On-Board DSRC (miniWSU), DC/DC Converter, Wireless Ethernet Router, Interim Data Storage

The On-Board DSRC, DC/DC Converter, Wireless Ethernet Router, and Interim Data Storage (together comprising the TRP Plate Assembly) were installed in the overhead compartment as shown in Figure 3-23.

Source: Battelle

Figure 3-23. TRP Plate Assembly Installed in Overhead Compartment

Power to these units was provided from the DC/DC Converter. The DC/DC Converter was connected to Vehicle Power which is accessible within the Vehicle Electronics compartment seen in the right picture in Figure 3-22 (above). The On-Board DSRC was connected to the Vehicle CAN Bus which is located in the Vehicle Electronics compartment. Access to vehicle power and Vehicle CAN Bus are shown in Figure 3-24 (below).

Source: Battelle

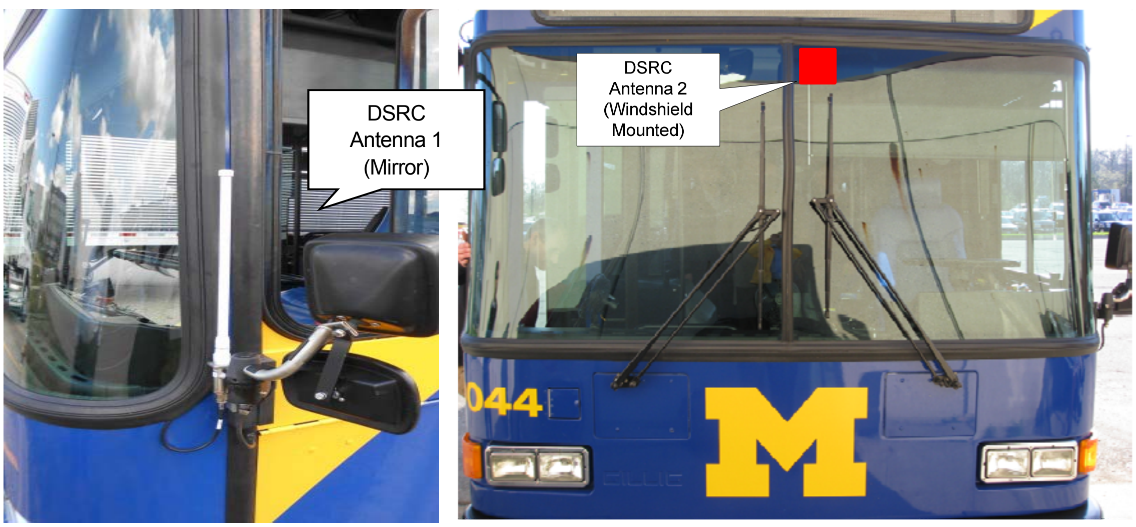
Figure 3-24. Vehicle Power (left), Vehicle CAN Bus Access Connector (right)

To maintain functionality of the miniWSU when the kill switch on the bus was activated, a small 12V battery (PS-1229) was installed into the wiring. The battery trickle charged when the kill switch was disabled. A diode was installed to prevent feedback. The battery was installed in the compartment with the TRP Plate Assembly. Double sided tape was used to secure the battery along with a large cable tie. Upon completion of install, the battery was hidden from view by the TRP Plate Assembly.

DSRC Antenna 1 and DSRC Antenna 2

In order to support the two new Transit-Specific Safety Applications, two separate DSRC antennas were selected, one to support each application. Each antenna has advantages and disadvantage that prevented using only one DSRC antenna. DSRC Antenna 1 (Mobile Mark PN: EC012-5800) was optimized to support the VTRW application, and DSRC Antenna 2 (Mobile Mark PN: EDN137-1600) was optimized to support the PCW application. These antenna's also served to support the three Basic Safety Applications.

DSRC Antenna 1 is a "whip" style antenna that was mounted on the driver side mirror in the upward position, as shown in Figure 3-25 (left). A "whip" style antenna was selected so that BSMs can be transmitted to and received from a DSRC-equipped vehicle traveling behind the transit vehicle or on the left of the transit vehicle. An antenna mounting bracket was fabricated to allow mounting onto the driver side mirror mounting arm. The antenna cable was routed behind molding and into the battery compartment. From the battery compartment, the antenna cable was routed to the overhead compartment shown in Figure 3-22 (above) and connected to the On-Board DSRC unit.



Source: Battelle

Figure 3-25. DSRC Antenna 1 (left), DSRC Antenna 2 (right)

DSRC Antenna 2 is a glass mounted antenna that is mounted on the inside windshield of the transit vehicle. This antenna has an antenna pattern that is primarily focused toward the front which is optimal for reception of the SPaT messages transmitted from the signalized intersection that is equipped to transmit pedestrian and crosswalk push button information. The location of Antenna 2 is shown in Figure 3-25 (right). The glass mount antenna allowed for easy installation without the need to penetrate the shell of the transit vehicle and had a shorter cable run back to the On-Board DSRC.

GPS Antenna and GPS Antenna Splitter

The TRP system and the DAS both have a need for GPS Antenna inputs. In order to minimize the number of antennas that are mounted on the exterior to the transit vehicle, a GPS Antenna Splitter was used to split the antenna signal to allow both TRP and DAS access to a GPS antenna. Since the DAS additionally requires a cellular antenna, a combined GPS/Cell antenna was used (Laird PN: GPST821/18503P). A hole was created for the GPS/Cell antenna in the roof of the bus. The GPS and cell cables were fed through the ground plane and the roof of the bus. A layer of RTV (Room Temperature Vulcanizing silicone) was placed between the ground plane and the bus, as well as between the GPS/Cell antenna and ground plane. Once the antenna was mounted, a layer of white RTV was placed around the ground plane. The GPS/Cell antenna was located 66" from the front of the bus and centered in reference to the sides.

The following pictures (Figure 3-26) show an exterior picture of the completed installation, and an interior view of the completed installation.

Source: Battelle

Figure 3-26. Exterior Post-Install (left), Interior Post-Install (right)

The GPS Antenna Splitter was installed in the overhead compartment behind the forward door. This allowed GPS antenna access for the TRP and the DAS. The TRP equipment was mounted in the overhead compartment behind the driver on the left side of the bus. The DAS was mounted in the overhead compartment behind the driver on the right side of the bus. The GPS antenna cables emerging from the splitter were routed to both the left and right sides of the bus. The cell cable follows the path of the GPS cable that is connected to the DAS.

TRP Testing

This section provides a summary of the testing that occurred prior to the introduction of the buses into the live Model Deployment. The Vehicle Install Test Plan, Applications Performance and Functional Test Plan, and Phase 3 Test Report provide comprehensive documentation on testing.

Installation Testing Overview

The purpose of installation testing was to confirm that the TRP equipment was properly installed and operational. After an unpowered wiring harness checkout was performed, a rudimentary powered checkout of the equipment was performed to confirm the system was operational, including:

- MiniWSU: Power light comes on. Status1 light come on. (Status2 light comes on if receiving BSM Messages from another unit.)
- IVD (tablet computer): Both TRP status indicators are Green.[5]
- GPS data: TRP "debug" screen indicates GPS data present.
- CAN data: TRP "debug" screen indicates CAN data present.
- DSRC antennas: Used spare TRP assembly installed in a remote vehicle to broadcast over DSRC; used laptop to access V2VMonitor program on miniWSU to check Received Signal Strength Indicator (RSSI) levels on DSRC1 and DSRC2 antennas (-65dB to -60dB borderline; >-60db good)

Equipment on all three buses checked-out as operational, with DSRC levels in the "good" range.

Functional Testing Overview

TRP Verification Testing was performed as documented in the Application Performance and Functional Test Plan, to verify the Hardware and Software requirements that are described in the TRP Applications Requirements document were met. Standard verification methods were used – Analysis, Demonstration, Inspection, and Test.

A tiered approached was used for testing to ensure that the TRP system met the requirements. There were four (4) classes of verification tests:

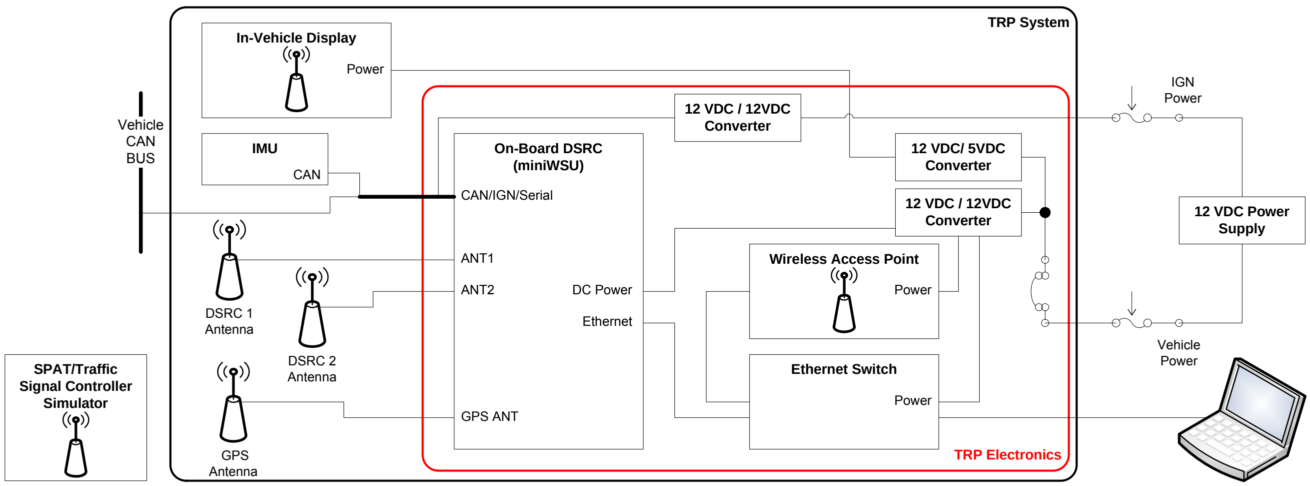
- Bench Tests of Software
- Controlled Environment Test
- Demonstration of Integrated Applications
- Verification by US Government/Test Conductor

The Test Plan describes step-by-step the various TRP tests with traceability back to each hardware and software requirement. It is organized according to the four classes of tests, and within each class it is organized by the four verification methods. Each individual test describes any necessary set-up, lists the test procedure steps, and identifies the criteria for passing the test. At the end of each test the TRP requirement which the test addresses is listed. A traceability matrix is also included as a chapter of the document, linking tests with requirements.

[5] The TRP default screen includes two status indicators in the lower right portion of the screen – the "TRP Data" indicator indicates whether the IVD is receiving data over the Transmission Control Protocol/Internet Protocol (TCP/IP) connection with the miniWSU required for the Transit-Specific Safety Applications, while the "Safety Data" indicator indicates whether the IVD is receiving data over the User Datagram Protocol (UDP) connection with the miniWSU required for the Basic Safety Applications.

Bench Tests of Software

Bench Tests of Software is a class of verification that uses a laboratory environment to stimulate the system of interest. The use of typical laboratory equipment such as multimeters, oscilloscopes, power supplies, simulators, and the like are used to perform verification. Figure 3-27 shows the test setup used for Bench Level Tests of Software unless indicated otherwise within a particular test.

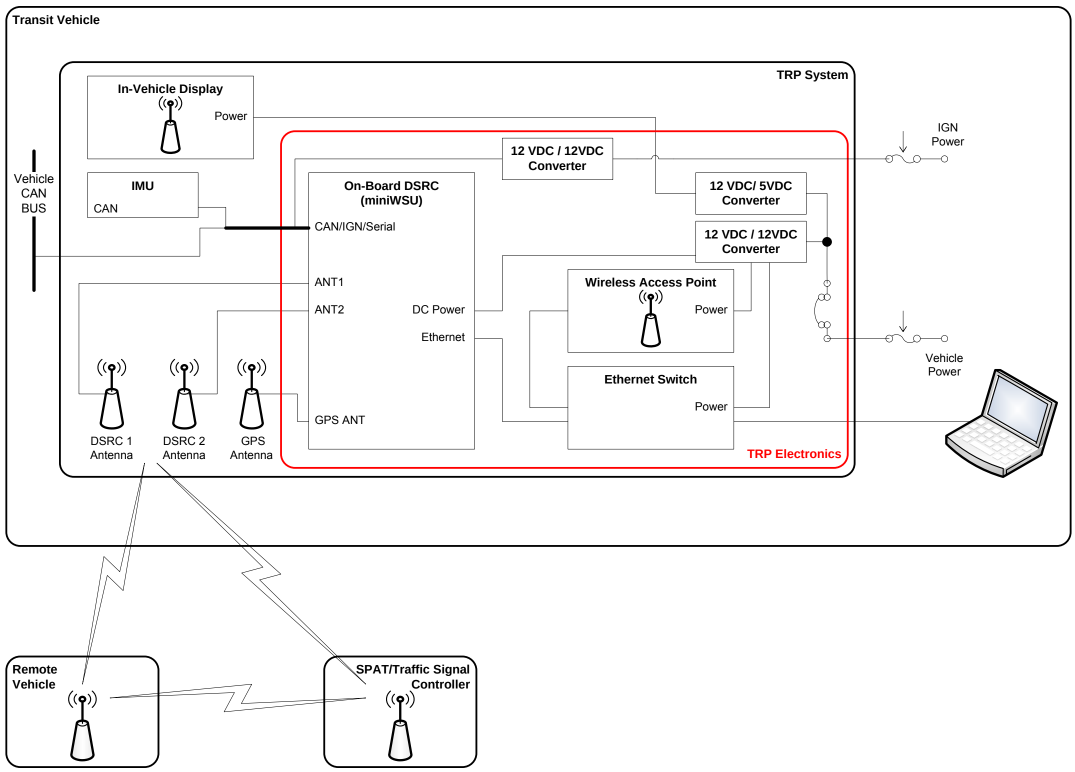


Source: Battelle

Figure 3-27. Bench Test of Software Setup

Controlled Environment Test

Controlled Environment Test is a class of verification that utilizes the system of interest in its intended application within a controlled environment. The controlled environment allows for verification of functionality in an environment that is as close to the intended environment while allowing for repeatability of tests. Figure 3-28 shows the test setup used for the Controlled Environment Tests unless indicated otherwise within a particular test.

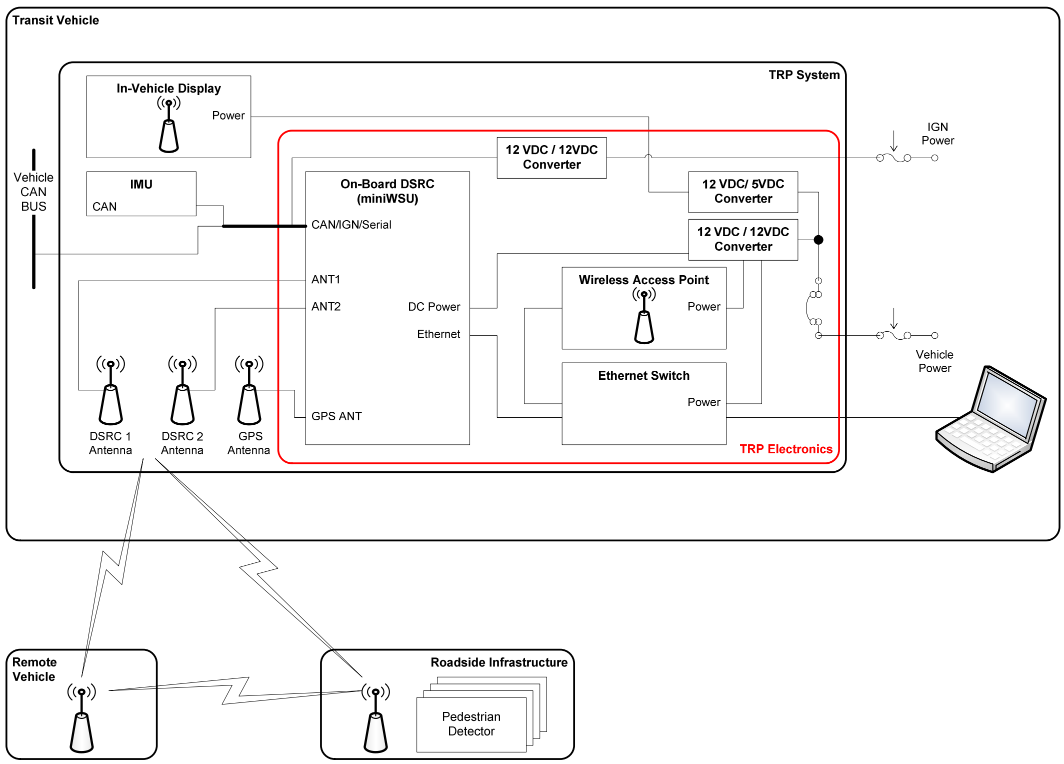


Source: Battelle

Figure 3-28. Controlled Environment Setup

Demonstration of Integrated Applications

Demonstration of Integrated Applications is a class of verification that utilizes the system of interest either within the intended environment or a representative environment to demonstrate functionality of the system. Figure 3-29 shows the test setup used for the Demonstration of the Integrated Applications unless indicated otherwise within a particular test.



Source: Battelle

Figure 3-29. Demonstration of Integrated Applications Setup

Verification by US Government/Test Conductor

Verification by US Government/Test Conductor is a class of verification where the system of interest is delivered to client and the client (US Government/Test Conductor) verifies functionality for interoperability within the deployment area. The purpose of this verification is to show that the TRP system is compatible to interoperate with other Model Deployment vehicles and RSE according to IEEE 802.11p and 1609.x standards and the J2735 message standards.

Interoperability Testing was an integral part of the Safety Pilot Model Deployment which verified the ability of vehicle-based and infrastructure-based devices to exchange data over DSRC utilizing SAE J2735 messages. In order to test the interoperability of multiple device types and multiple device suppliers the testing consisted of conducting preliminary controlled bench tests followed by field tests designed to represent how the devices would interact in a production environment. Interoperability Testing was held in three stages, with the first stage focused on vehicle-to-vehicle testing and the second stage focused on vehicle-to-infrastructure testing. Stage I of the Interoperability testing took place prior to the Pre-Model Deployment Dry-Run and Stage II will took place immediately following dry-run. Based on the results of the Stage II, the Test Conductor conducted a third round of

Interoperability Field Testing. During Stage III, devices that either failed tests or did not support functionality during Stage II Field Test were regression tested to confirm earlier issues had been resolved. The Test Conductor also tested applicable devices to ensure they provided an appropriate alert for Curve Speed Warning.

Demonstration Testing Results

Prior to testing of the TRP in its intended environment in Ann Arbor, a demonstration of was performed in Columbus, Ohio, on June 14, 2012. This demonstration used a Central Ohio Transit Authority (COTA) bus with TRP installed, and successfully demonstrated the EEBL and FCW applications. The purpose of this demonstration was to show that the TRP was ready for installation and further testing on the three UM Transit Vehicles in Ann Arbor. Based on the successful outcome of the COTA bus demonstration in Columbus, USDOT approved the project to move forward with TRP installation on the UM Transit Vehicles in Ann Arbor.

For the original deployment, demonstration testing of the TRP in its intended environment was performed on two separate occasions. An initial test was unsuccessfully performed on December 11, 2012, due primarily to issues with the Roadside Equipment at the Fuller Avenue and Medical Center Drive test intersection. Following correction of issues, a retest of the TRP was successfully performed on January 31, 2013. The second demonstration test was successful in demonstrating the operation of all TRP elements, including the two Transit-Specific Safety Applications developed for the TRP. All expected safety alerts were shown for both the PCW and VTRW applications at the appropriate times. At the end of these demonstrations, the TRP with the five safety applications became operational and started providing alerts to bus drivers in the Model Deployment on the three TRP-equipped buses on January 31, 2013. The original deployment testing is further detailed in the following paragraphs.

RSE Instability during Initial Test

During the initial test, the RSE at the intersection of Fuller Avenue and Medical Center Drive was found to be unreliably broadcasting the SPaT and MAP messages. Messages would broadcast for a short amount of time, stop, and only broadcast again once the system was reset. Another issue was that the MAP message, which contains lane geometry used to determine the bus lane, was inaccurate. A third issue was that pedestrian detectors sometimes falsely reported detections when vehicles were moving through the crosswalk.

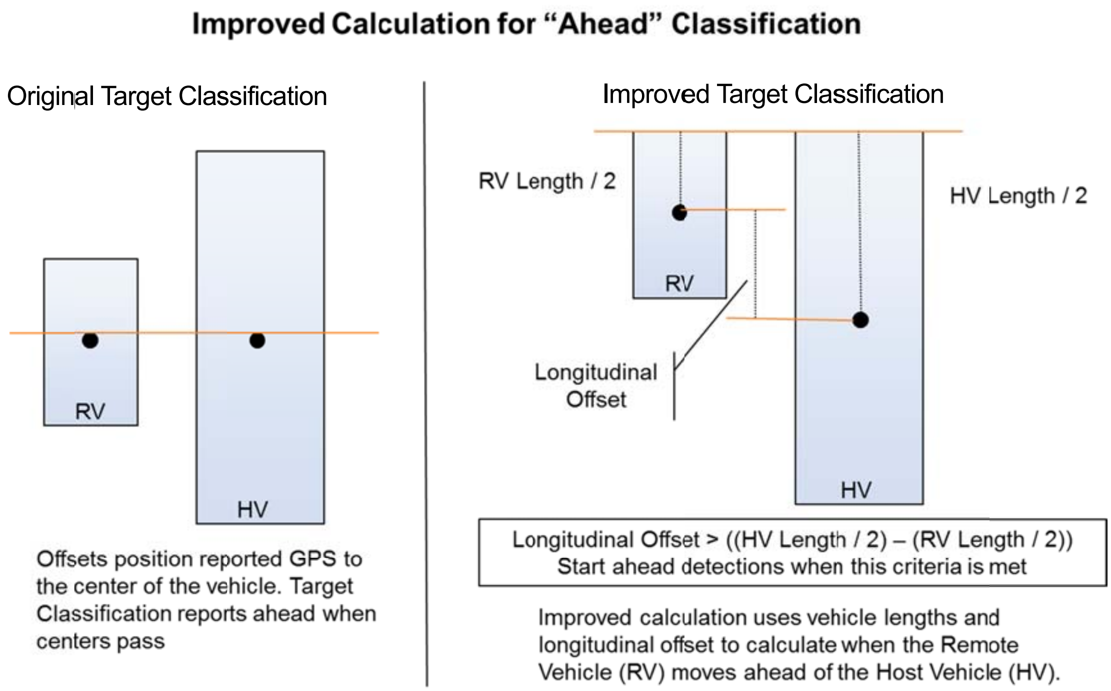
MiniWSU Instability during Initial Test

The miniWSU was found to have issues with boot up and power down, which resulted in the device becoming non-responsive until a hard reset was done. The miniWSU also stopped responding when it received a BSM from Cohda OBE. The demonstration of the VTRW application also showed that the classification of the remote vehicle was changing from behind to in front of the bus too early, and that the classification of the remote vehicle as turning right was inaccurate.

Correction of Initial Test Issues

The Battelle team worked with the Test Conductor, UMTRI, to isolate and correct the issue that caused the RSE to stop broadcasting SPaT and MAP, and to correct the lane geometry in the MAP message to more closely match the actual lanes. Battelle worked with the pedestrian detector manufacturer, MS Sedco, to reduce the number of false detections by modifying detector configuration settings. Settings changes included reduction of the detection speed threshold, increase of the verification time, and changing from bi-directional detection to unidirectional depart mode.

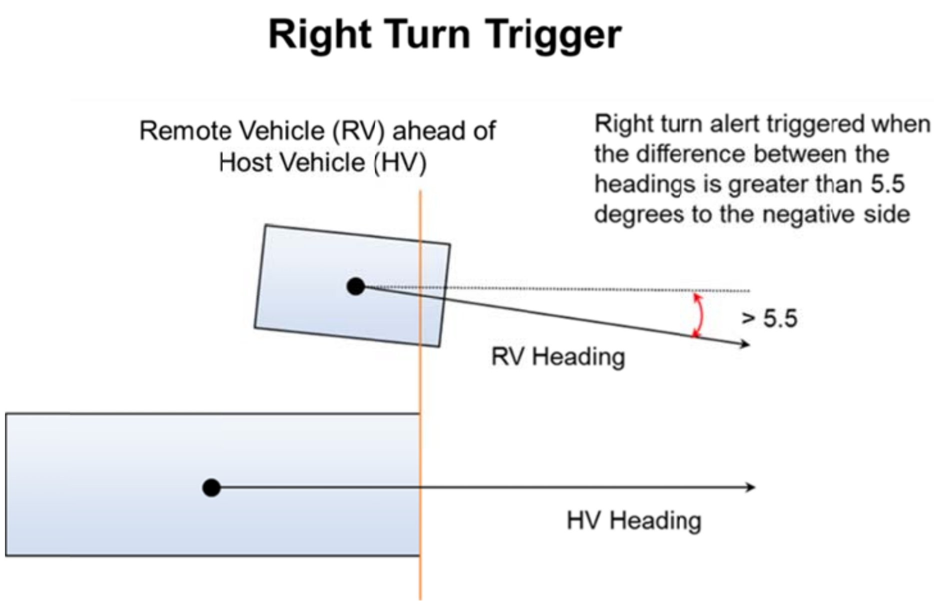
Battelle worked with DENSO to correct issues with the miniWSU. The miniWSU on bus 3046 was replaced since it was determined to be an early generation unit not suitable for deployment. MiniWSU firmware on all TRP units was updated to address the power up/down glitch, and to support BSM communication with Codha-equipped vehicles. For VTRW processing, the miniWSU algorithm was changed so that the transition of the remote vehicle to “Ahead” classification occurs when the front of the remote vehicle passed the front of the host vehicle as shown in Figure 3-30.



Source: Battelle

Figure 3-30. Improved Calculations for "Ahead" Classification

The VTRW right turn classification was originally based on the projected path from the BSM. This was changed to instead use the heading difference between the remote vehicle and the host vehicle as shown in Figure 3-31.



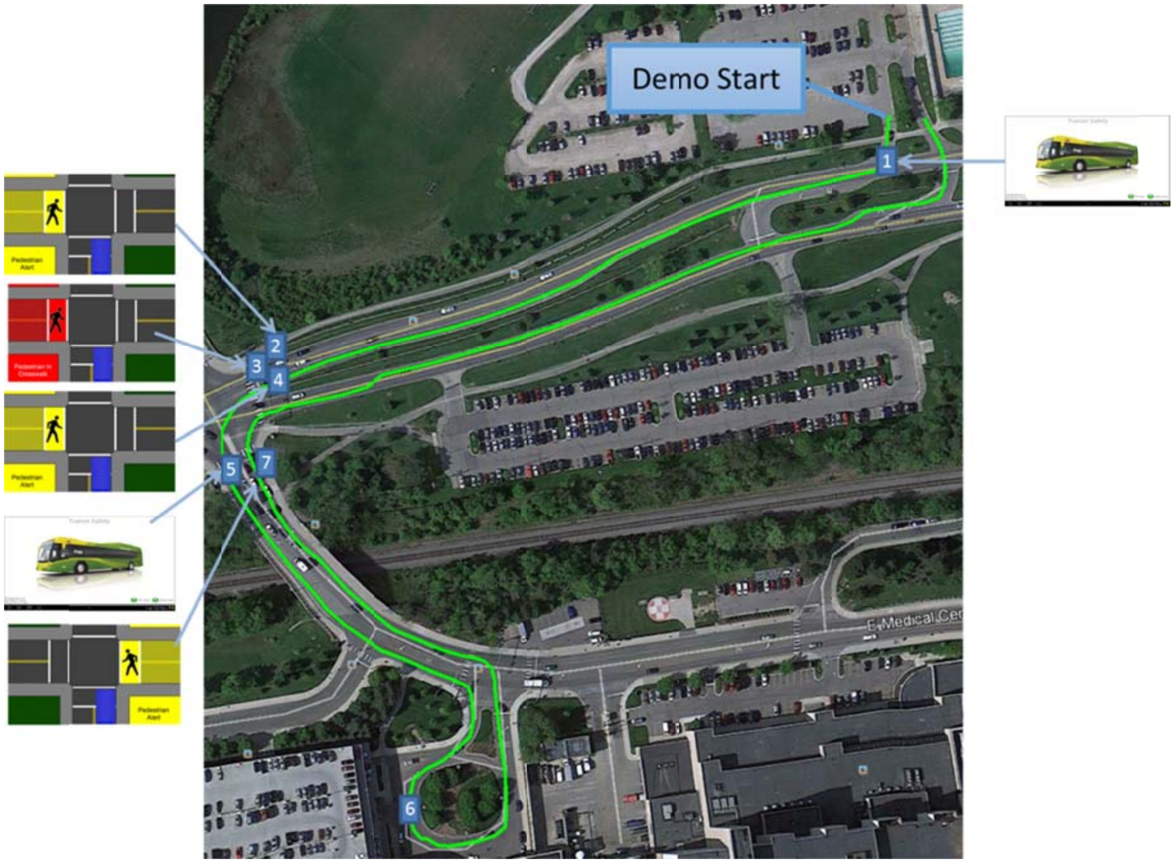
Source: Battelle

Figure 3-31. Right Turn Trigger

PCW Demonstration – Successful Retest

As an example of the successful demonstration, one PCW scenario from the retest is described in the following steps and depicted in Figure 3-32.

1. The bus headed west on Fuller Avenue, towards the intersection.
2. The pedestrian pushed the crosswalk call button to cross Medical Center Drive, as the bus was stopped at the red light. The IVD immediately changed from the default intersection image to the intersection image with the yellow alert on the left crosswalk.
3. While the traffic signal was red, the pedestrian carefully walked just far enough into the street to be detected by the pedestrian detector to show the alert change from yellow to red on the IVD.
4. Once the pedestrian was back on the sidewalk and out of the pedestrian detector range, the IVD went from its red warning to the yellow alert.
5. The bus made the left turn and the yellow alert image displayed until the bus had completely left the intersection.
6. The bus turned around again at the medical center and made one more pass through the intersection preparing to make a right-hand turn onto Fuller Avenue.
7. Before the bus turned right, the pedestrian pressed the crosswalk call button to cross Fuller Avenue and the IVD then displayed the yellow alert on the right crosswalk.



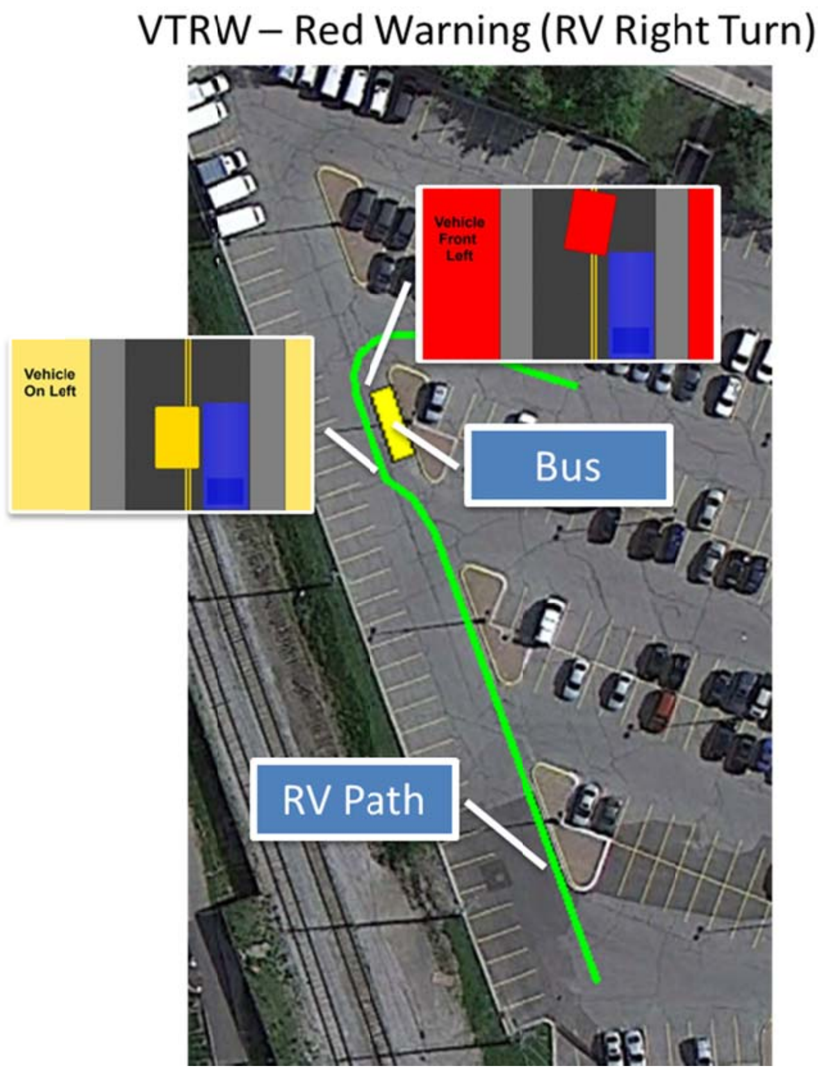
Source: Battelle, Google Inc.

Figure 3-32. PCW Demonstration Example

VTRW Demonstration – Successful Retest

As an example of the successful demonstration, one VTRW scenario from the retest is described here and depicted in Figure 3-33.

A bus stop was set up in the southeast corner of the Crisler Arena parking lot to avoid interfering with scheduled bus activities at a live, actual bus stop. The demonstration showed four types of maneuvers around a bus that was stopped at a bus stop, and the resulting VTRW alerts and warnings. The demonstration was conducted with a remote vehicle traveling around the bus. As an example of one of the four types of maneuvers, the remote vehicle started behind the bus, passed the bus on the left, and then turned right in front of the bus. This simulated a vehicle passing and turning right in front of a bus on a two-lane road. The yellow VTRW alert was displayed when the remote vehicle changed from behind to behind left, then changed to the red VTRW warning once the remote vehicle started to turn in front of the bus as shown in Figure 3-33.



Source: Battelle, Google Inc.

Figure 3-33. VTRW Demonstration Example

The VTRW test plan was executed successfully in its entirety. It was then decided to test a real bus stop under live conditions. This test was unsuccessful, resulting in the action to verify all designated bus stops were properly configured within the TRP system. Battelle found there were inaccuracies in the geo-fence polygons for some of the designated bus stops. Changes were installed and tested on February 22, 2013, verifying each bus stop operated as expected.

On-Board Data Acquisition System

The On-Board Data Acquisition System (DAS) and its integration are documented in the following reports. This section provides a DAS summary based on these reports.

- TRP DAS Documentation

- Architecture and Design Specification
- Vehicle Install Test Plan

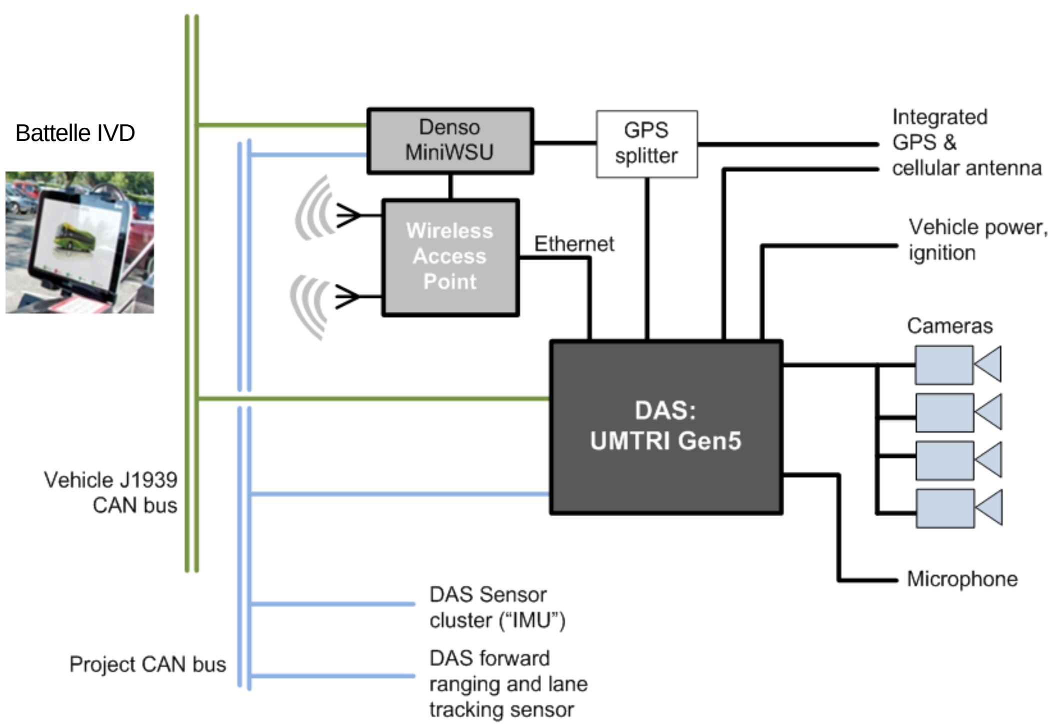
The DAS is TRP supporting equipment that is installed on the transit vehicle. The IMU, also supporting equipment and used with the DAS, is also covered in this section. The DAS and the IMU were provided by UMTRI, under a subcontract with Battelle.

DAS Roles

The primary purpose of the DAS is to collect data during the naturalistic use of the TRP vehicles. These data include the Basic Safety Application alert flags, sensor inputs and other factors that support the alert decision-making, and data which describe vehicle travel and driver actions. Signals from the vehicle's data bus, wireless communication packet information exchanged between the TRP vehicles and nearby vehicles equipped with connected vehicle systems, video image streams, and cabin audio surrounding the safety application alerts are recorded by the DAS. The DAS data along with IVD data enable TRP performance analysis by Battelle and the Volpe IE. A secondary DAS function is to remotely monitor the functionality and health of the vehicle as well as much of the TRP system (excluding the TRP IVD and wireless access point).

DAS Architecture

Figure 3-34 shows elements of the DAS as well as TRP elements that interface with the DAS. Note that there are TRP elements that do not interact with the DAS, which are not shown.



Source: UMTRI

Figure 3-34. Schematic of the DAS within the TRP Architecture

The DAS main module is shown as a large rectangle in the center of Figure 3-34. The DAS main module interfaces with several elements. Starting at the lower left in the figure and going clockwise around the figure, the interfaces to the DAS include:

- Project CAN bus. This bus serves to connect the DAS to an UMTRI sensor cluster that contains a multi-axis accelerometer and a yaw rate sensor. The TRP project CAN bus also connects the DAS to a vision-based ranging and lane-tracking sensor that views the scene in front of the transit vehicle and provides measurements of range to vehicles ahead and the transit vehicle's position in the lane. The mini-WSU is also on this CAN bus in order to access the sensor cluster data.
- The vehicle's factory-installed SAE J1939 CAN bus. The J1939 bus carries a host of signals between factory-installed elements on the vehicle, including basic signals such as speed, brake switch status, and sometimes other signals such as headlamp or turn signal status.
- A hardwired Ethernet connection to a combination wireless access point and Ethernet switch. This provides the DAS with direct hardwire access to the DENSO miniWSU device that serves as the Basic Safety Application platform, as well as the platform for all V2V and V2I communications. This connection provides the DAS with all Basic Safety Application data (including driver alerts and supporting information), as well as sent and received V2V and V2I messages. The V2V and V2I messages are sent by the miniWSU in a form which is very close to Packet Capture (PCAP) files.
- GPS signal. The miniWSU and the DAS share a single GPS antenna that was installed for the TRP project. The signal runs through an active signal splitter to provide separate feeds to the DAS and the minWSU. There are separate GPS receivers within the miniWSU and DAS.
- Cellular modem antenna. Upon each key-off, the DAS sends a subset of data via commercial cellular data channels to servers at UMTRI to support the remote monitoring of the DAS and the systems that are directly interfaced with the DAS. There is a cellular modem antenna on the vehicle roof.
- Video cameras. Four video cameras are mounted on the vehicle to capture the activity outside and inside the vehicle.
- Vehicle ignition and power. These signals are used -- with significant logic and filtering – to trigger the powering up and down of the DAS and its peripheral devices.
- Microphone. A microphone is mounted near the IVD as a way of double-checking that driver alerts were actually audible.

Note that there is no direct or indirect connection with the TRP IVD, which serves as the transit-specific application computing platform and driver interface. The TRP IVD separately logs transit-specific application data. The TRP IVD and the DAS both log a GPS timestamp that is provided by the miniWSU, allowing the data on the IVD and DAS to be synchronized in post-processing.

DAS Components

This section describes the individual DAS-related TRP elements in more detail and shows the mounting location on the TRP vehicles.

DAS Main Module

The UMTRI DAS units used in the TRP project are the latest generation of DAS called the “Gen5” DAS. This latest evolution is more compact, more efficient, with a capability to record hundreds of signals simultaneously and capture multiple video streams and audio. In addition to the three TRP buses, the UMTRI Gen5 DAS was used on 100 ASD-equipped vehicles and eight heavy truck RSD vehicles in the Safety Pilot Model Deployment. Figure 3-35 shows the DAS Main Module mounted in the right side air duct that runs lengthwise along the ceiling of the vehicle’s cabin.

Source: UMTRI

Figure 3-35. UMTRI Gen5 DAS, Mounted in Air Duct

The DAS contains a combination of UMTRI-designed and commercial off-the-shelf elements. The Gen5 DAS has been optimized to reduce size and costs for the connected vehicle project set, and is intended for long-term unattended operation. The DAS uses a single-board computer, with power managed via a sophisticated power controller board and backup battery. The DAS features multiple CAN bus inputs, multiple video inputs, audio, gigabit Ethernet ports, USB ports, automotive data storage devices, a GPS receiver, and a cellular modem. The DAS parses, time-stamps, and stores hundreds of variables using a COTS CPU and automotive-grade data storage media. The DAS can store TRP data for several weeks at a time. The DAS generates files that are stored onboard the vehicle, and are then downloaded periodically, so that the data can be loaded into databases suitable for analysis or delivery to the IE. A cellular modem enables a subset of critical data to be sent over the air, including numerical and video data, to allow remote monitoring of the DAS and systems that interface with the DAS.

Sensor Cluster (IMU)

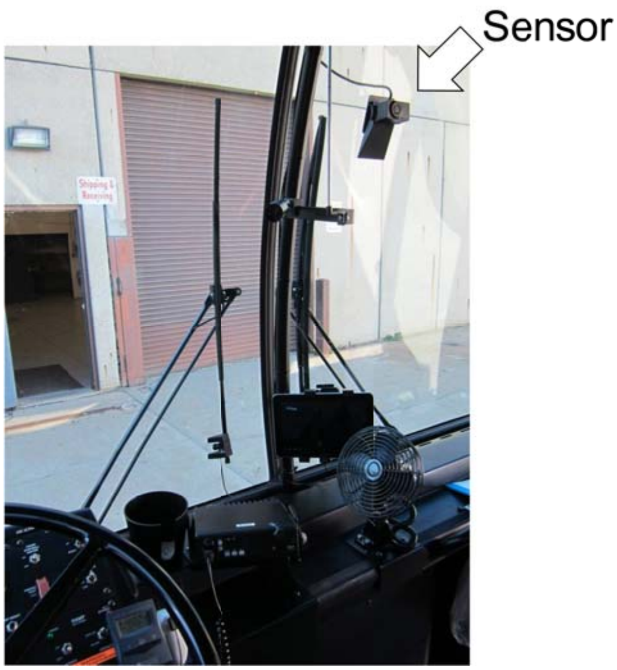
The sensor cluster continuously measures yaw rate and lateral and longitudinal acceleration, and provides those data to the DAS and the miniWSU via the TRP project CAN bus. The sensor cluster is a production unit from a Tier 1 supplier, and is installed in a watertight enclosure and attached to the underside of the integrated chassis/body of the bus as shown in Figure 3-36. The size of the enclosure is approximately 6" x 4" x 3". Various installation configurations were investigated, and this installation was selected as the best compromise between the goals of minimizing sprung-mass coupling effects that occur when mounting on the body (e.g., body roll appearing as lateral acceleration) and avoiding the confounding effects of axle shimmy for an axle-mounted system. The figure shows the cluster enclosure is mounted behind a frame channel for added protection. The sensor cluster is powered directly from the vehicle via switched power.

Source: UMTRI

Figure 3-36. Protective Enclosure with Sensor Cluster, Mounted to Bus Frame

Forward-Ranging and Lane-Position Sensor

The vision-based module is used to measure the distance to vehicles ahead, as well as estimating the transit vehicle's position within the lane. This device, from the vehicle component supplier Mobileye, is used as a sensor instead of radar because the vision-based sensor also provides lane position, does not protrude from the front of the vehicle, and is straightforward to install. The sensor provides information about the forward scene such as the number of same- and opposite-direction vehicles, the relative distance and speed of other vehicles, and relative location of vehicles with reference to the host vehicle. Additionally, the sensor also has the ability to track lane boundary markers and provide measures of the host-vehicles position with respect to a lane. Figure 3-37 shows the Mobileye installation on the windshield of the bus. This sensor requires a calibration process during installation using a calibrated visual target.

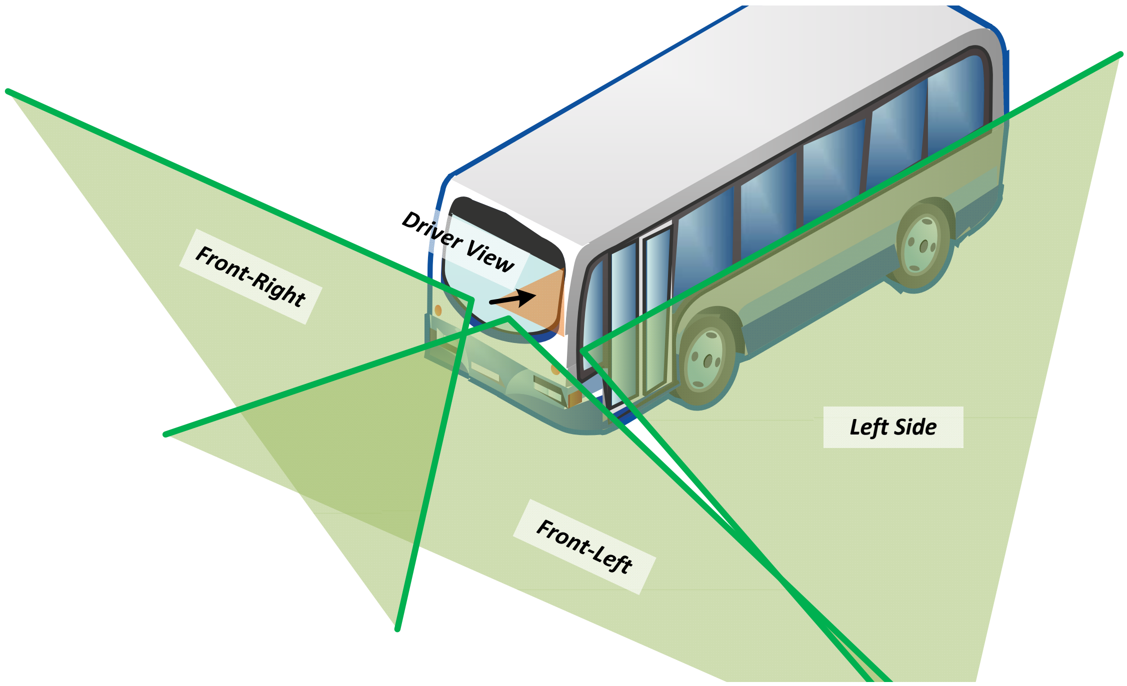


Source: UMTRI

Figure 3-37. Forward-Ranging and Lane-Position Sensor Installation

DAS Video Cameras

Four video cameras are installed in the TRP vehicles as part of the DAS system. Two cameras look forward through the windshield so that their combined images provide wide-angle coverage of the forward scene. A third camera mounted on the outside rear-view mirror looks sideways and rearward down the driver's side of the vehicle. A fourth camera, with infrared illumination, is mounted inside, near the windshield, to provide a view of the driver's face and shoulders. These fields of view are illustrated in Figure 3-38. The camera mounting locations are shown in Figure 3-39 and sample images are shown in Figure 3-40. The cameras are grey-level ("black and white") to provide better night-time imagery and to produce a more manageable volume of data. The camera frame rates are 5 Hz and the images are compressed spatially and temporally.



Source: UMTRI

Figure 3-38. Illustration of DAS Cameras Coverage

Source: UMTRI

Figure 3-39. Locations of DAS Cameras

Source: UMTRI

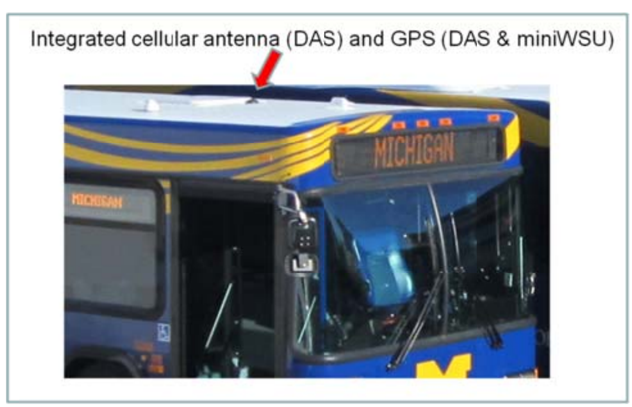
Figure 3-40. Samples of DAS Views

DAS Microphone

A compact microphone that is less than ¼” in diameter is installed just under the IVD in order to hear audio from alerts. This provides a confirmation, should a question arise, of whether a miniWSU-issued alert was actually presented.

DAS GPS and Cellular Modem

The DAS has its own separate GPS receiver. In addition to location and path information, the GPS provides accurate and high-resolution timing data that is used to synchronize all data elements, including host-to-remote vehicles data. The GPS unit is built into the DAS (shown in Figure 3-41 before installing into the DAS enclosure) and it is connected to an integrated GPS/cellular antenna that is mounted on the roof of the bus (also in Figure 3-41). The cellular modem that is within the DAS main module is connected to the integrated antenna on the bus rooftop. The modem enables the remote monitoring of the status of the DAS as well as the general health of the TRP system and the bus activity.



Source: UMTRI

Figure 3-41. DAS GPS receiver (left) and GPS/Cell Modem Antenna Location (right)

DAS Data

Monitoring Vehicle Travel and Fleet Health with DAS

At the end of each ignition cycle (or “trip”) the DAS sends a compact set of data over the cellular modem. These data include snapshot images to verify camera operation, summary statistics about the trip (e.g., speed, distance, braking, etc.), statistics about forward objects (“targets”) from the Mobileye, statistics about other connected vehicles/RSEs that were encountered, summary information about alerts (e.g., who, where, encounter dynamics, etc.), and various diagnostic parameters about the vehicle, the GPS, amount data recorded, etc.

These data allow monitoring of the vehicle operation and the overall health and functionality of the DAS and the elements that send data to the DAS, whether directly or indirectly.

DAS Data Archive

The main DAS data set is much more comprehensive than the data sent by cellular modem. The main data set was downloaded by UMTRI staff during periodic visits to the bus depot, with a month’s worth of data requiring approximately an hour or more to be moved from the DAS to a laptop via a hardwire Ethernet connection.

TRP Driver Training

Driver Training is documented in the following reports that were generated under this contract. This section provides a Driver Training summary based on these reports.

- Driver Training Exercises Test Plan
- Driver Training Summary Report

Training Plans

Approach / Overview

The plan for training the University of Michigan Transit (UM Transit) drivers who operated the three TRP-equipped buses is documented in the TRP Driver Training Exercises Test Plan. The approach was developed in consultation with the Safety Pilot Model Deployment Test Conductor, U.S. DOT, and UM Transit drivers. The overall approach, per the direction of the Test Conductor and University of Michigan, was designed to accommodate a relatively large number of trainees utilizing only classroom training exercises. The basic approach consisted of a series of 60-minute classroom training sessions, each with between two and six drivers, and featuring a short video on connected vehicles and the Safety Pilot Model Deployment, a PowerPoint presentation on the TRP system, and a Battelle team trainer to answer questions. A single-page, two-sided, laminated “TRP Quick Reference Guide” was also provided to each trainee as a compliment to the classroom training. TRP driver training covered the following major topics:

- Background on connected vehicles and the Safety Pilot Model Deployment
- Overview of the TRP System
- Use of the TRP System, including a description of the default, “ready-mode” appearance of the IVD; a description of the full range of potential alerts and

warnings that could be presented to drivers associated with all five of the TRP safety applications to be deployed; and procedures for reporting problems or concerns.

- Data collection activities, including the on-board Data Acquisition System (DAS), surveys and focus group(s), and use and protection of data.

Related Driver Activities

The following activities are not a component of TRP driver training but are related in that they pertain to the TRP drivers. These activities are briefly summarized here to provide additional context for the driver training:

- Institutional Review Board – The data collection from human subjects associated with the TRP Safety Pilot Model Deployment activities was addressed through the University of Michigan Institutional Review Board (IRB) process. That process was led by the Safety Pilot Test Conductor. The Battelle team coordinated with the Test Conductor such that completion of the University of Michigan IRB process could serve to satisfy Battelle's IRB requirements.
- Driver Consent Forms – The Safety Pilot Test Conductor was responsible for obtaining consent from the drivers that would, or may, operate the TRP-equipped buses. Each driver that was invited to training was asked to sign a consent form developed by the Test Conductor that outlined the major parameters associated with the drivers' participation in the TRP program, focusing on the data that would be collected and how it would be used and protected.

Recruitment and Scheduling

Drivers were recruited for training by the UMTRI Test Conductor team. An UMTRI staff member was stationed in the driver's room at UM Transit and as drivers came and went he engaged with them, providing them a copy of the UMTRI driver consent form, inviting them to participate in training, and scheduling them for a training session. Drivers were asked to review the consent form prior to the training and informed that UMTRI would review the consent form and ask the drivers to sign in at the start of the training session.

Training Implementation

Training Sessions

Training sessions were conducted in a conference room at UM Transit offices. The UMTRI staff member who had recruited the drivers was present, as was a Battelle TRP trainer. Each session began with brief introductions and the UMTRI staffer reviewing the consent forms and asking the drivers to sign the form. Upon signing, each driver was provided $50 in cash by the UMTRI staffer, as a compensation for their participation in the training. As part of the consenting process, each driver was informed that there would be opportunities for them to provide feedback on their TRP bus operating experiences via a survey and/or focus group and the consent form included a check box indicating whether the driver would like to be contacted later, by UMTRI, to be asked to participate in those feedback activities.

Driver training for the original deployment (February through September 2013) was conducted in two periods – an initial round of training in early December 2012, and then in a series of supplemental sessions in January 2013. The supplemental sessions were requested by UM Transit as they wanted to train as many drivers as possible to facilitate their ability to restrict operation of the three TRP buses to drivers who had been consented and trained, thus maximizing the amount of data collected that could be utilized for evaluation (data from non-consenting drivers cannot be used in the evaluation).

Driver training for the TRP redeployment (February/March 2014) was conducted in January2014. This training was based on the original training material, with modifications to focus on the TRP refinements that were fielded for the redeployment.

Drivers Trained

A total of 50 drivers were trained during the initial round of training on December 6 and 7, 2012. An additional 11 drivers were trained through the supplemental training activities, as of February 13, 2013. Of the 61 drivers trained, 32 of them were full-time drivers and 29 were part-time drivers. A total of 35 drivers were trained for the 2014 redeployment.

Driver Feedback

Generally, there was a moderate amount of questions and comments from the drivers during the training sessions. For example, in a typical 4-driver session, there were usually a half dozen or so questions and comments. A number of drivers had seen the TRP IVD (tablet computer) when they were installed in the TRP buses between August and December 2012, operating in “cloak mode” (the three Basic Safety Applications were running but no alerts were being issued to drivers) and some of their questions and comments were informed by that experience.

Most questions and comments focused on the same few topics, as follows:

- How the Dedicated Short-Range Communications technology used on the TRP and other Safety Pilot Model Deployment vehicles works, and why alternative technologies like those now commercially available on vehicles (e.g., on-board sensors) are not being used (an explanation was provided).
- Whether it would be possible to relocate the TRP IVD from its planned location on the dash, to the right of the driver, to some other location if drivers found the location problematic (the answer was that we would welcome any further feedback once the operations period began and would consider changes if necessary).
- Whether the volume level of the TRP audible alerts could be altered if necessary, for example if the drivers find it too loud or if passengers hear and/or see the alerts and may conclude that the driver is driving poorly or quiz the driver about the alerts (the answer was yes, we could alter the alert volume and that we would welcome feedback, including any responses needed to address questions from passengers).
- Whether there could be anything done to reduce the glare on the TRP IVD, if necessary (the answer was yes, and we would welcome feedback).
- Whether the speed threshold for issuing Curve Speed Warning alerts on the one TRP location on Bonisteel Boulevard (originally set to 30 miles per hour, 5 miles over the posted speed limit) could be modified if drivers were getting a lot of alerts (the answer was that we could adjust the setting if necessary).

TRP Deployment

As noted in the Project Overview, the TRP project had four deployment phases as follows:

- Phase 1: FCW, EEBL, and CSW deployed – In August 2012, basic integration on the three UM Transit vehicles was completed, and live testing began in a cloaked mode (alerts were not presented to the driver).
- Phase 2: Data Acquisition System (DAS) deployed – In October 2012, DAS integration on the three UM Transit vehicles was completed, and live testing continued in a cloaked mode.
- Phase 3: PCW and VTRW deployed – In January 2013, PCW and VTRW integration on the three UM Transit vehicles was completed, and eight months of full-up live testing began, uncloaked for data collection and evaluation.
- Phase 4: TRP revisions deployed for Phase 3 lessons learned – In January 2014, TRP revisions were integrated on the three UM Transit vehicles, and in February 2014 one month of full-up live testing began, uncloaked for data collection and evaluation.

Battelle tasks during TRP deployment included repairing and maintaining the retrofit packages; periodically offloading, quality checking and transmitting to the Volpe Center the operating data from the DAS and the IVD; updating system documentation, and removing and providing to U.S. DOT the retrofit packages at the conclusions of the Model Deployment.

The results of TRP deployment are embodied in the operating data collected – from the three TRP Transit Vehicles, and from drivers of these vehicles. This section first summarizes the data process and data collected from the TRP Transit Vehicles, and then summarizes the results of two driver focus groups and one driver survey. Data from the original eight month deployment (Phase 3) and the one month redeployment (Phase 4) are included. (Data from Phase 1 and Phase 2 were not used for TRP evaluation purposes.) This information is covered in additional detail in the following deliverables:

- Data Dictionary Document
- Monthly Data Reports and Data
- Transit Operator Focus Group Summary Report
- Transit Operator Focus Group II Summary Report

Data Process

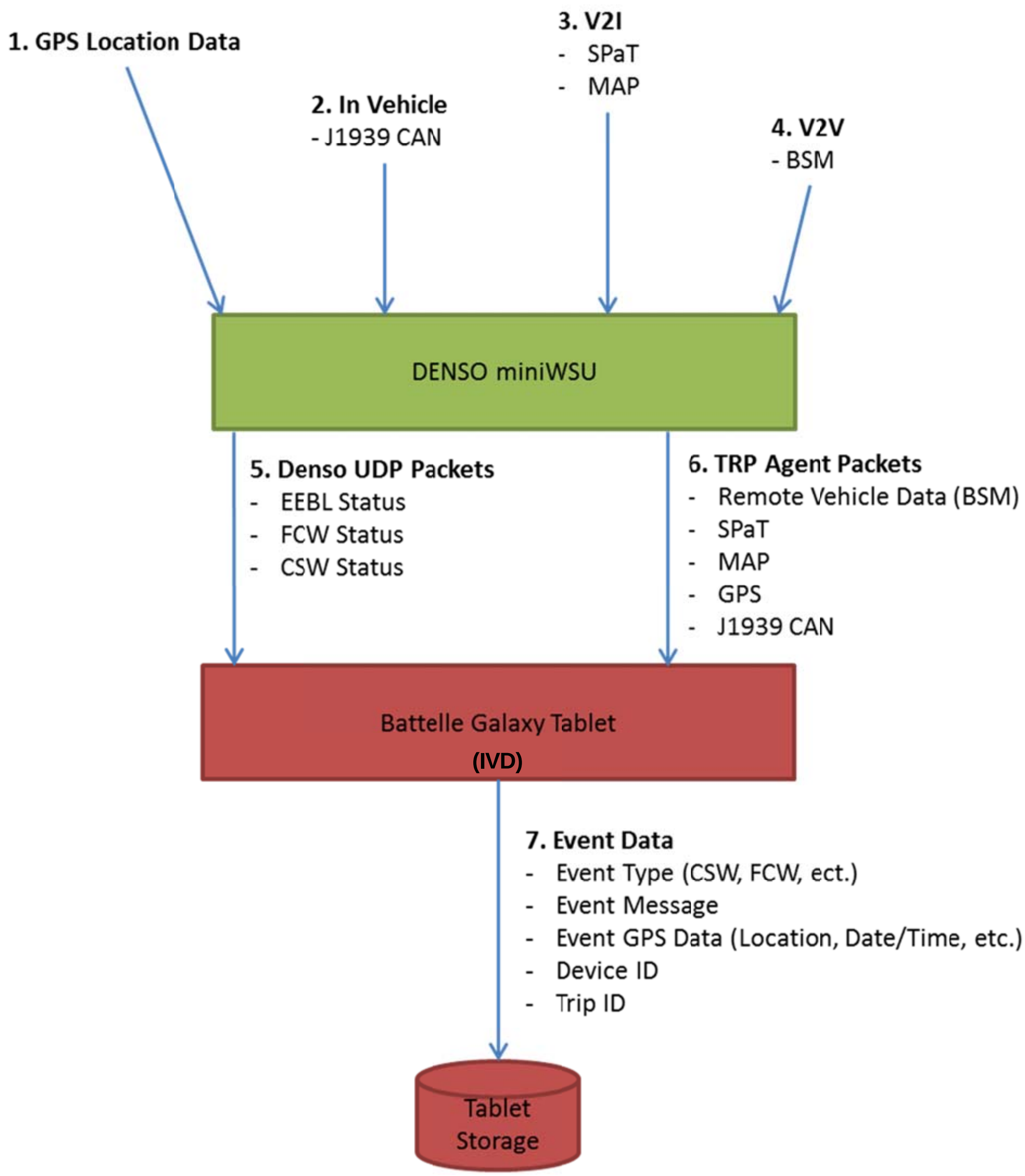
Data Sources Overview

A requirement of the TRP project, as well as of the overall Safety Pilot Model Deployment program, was the capture of data elements related to the operation of the TRP system. This data was captured for the purpose of conducting an evaluation on the effectiveness of the TRP applications as well as for subsequent research that may be conducted.

The DAS collects and records data from both its own interfaces to sensors, as well as information received from the WSU. The TRP IVD (tablet computer) similarly receives data from the WSU as well as data that is generated from within the IVD device itself. Figure 3-42 defines the data elements and the flow through the major components of the TRP system. The WSU serves as the data broker for the TRP system and receives information from the vehicle via CAN interface, location information over GPS, and Vehicle-to-Vehicle and Vehicle-to-Infrastructure information from DSRC. The WSU makes the received information available to the TRP Agent application on the WSU via shared memory. The TRP Agent application on the WSU subsequently sends TCP/IP packets containing vehicle location, J1939 CAN data, and remote vehicle information over the local network interface to the IVD. The IVD then uses the received data from the TRP Agent on the WSU to determine the current VTRW and PCW events.

The information for displaying a FCW, EEBL, and CSW alerts is generated from the V2I and V2V data input into the WSU. The WSU broadcasts a UDP packet containing the current state of the FCW, EEBL, and CSW applications, including alert information to the IVD over the local network. The IVD takes the received data and processes it to find the alert with the highest priority from the FCW, EEBL, and CSW applications.

The alert information is then processed by the IVD, and the alert with the greatest priority is displayed to the driver of the transit bus. When a new alert is presented by the IVD, a message containing the event information including event type, event location, trip id, and device id is logged to a file in local storage. Those logs are pulled off and processed into Comma Separated Values (.csv) files that are then imported into the Volpe database.

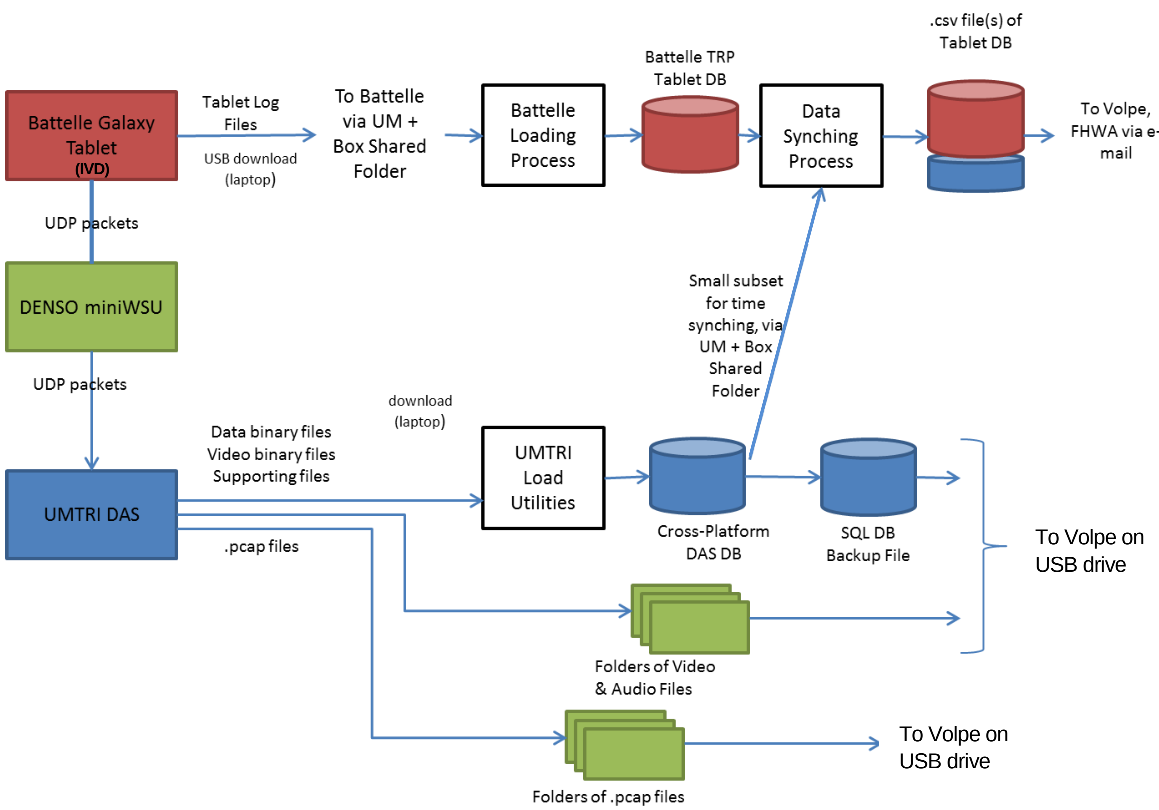


Source: Battelle

Figure 3-42. TRP Data Flow

Data Processing Overview

UMTRI collected and processed data from the TRP equipped buses on a recurring basis, roughly near the end of each month. The data collected consists of logs from the Battelle TRP IVD device and four different data sets from the DAS, including WSU data (in .pcap format), video data and the captured lat/long and other data, in binary format. Data from the DAS was processed and forwarded to Volpe in the same manner as all other UMTRI DAS-equipped vehicles. UMTRI processed this data and forwarded the collected data in database form to the Volpe team using external hard drives as shown in Figure 3-43. Additionally, as shown in the figure, a small subset of DAS data was provided directly to Battelle in order to facilitate our synchronization of the TRP IVD data with that of the DAS, and for Battelle assessment of TRP performance. This subset of data was made available by UMTRI via a shared folder on the UM + Box site to the Battelle team. This same UM + Box was used to provide the retrieved TRP IVD logs files to Battelle. Battelle processed and analyzed the data from the Battelle TRP IVD database, and added the necessary DAS time and DAS trip information from the UMTRI feed to the IVD logs in order to align the IVD event data to the collected UMTRI DAS data. Upon completion of the IVD event log processing and synchronization, Battelle prepared and submitted to Volpe and FHWA, via email, two comma-separated values (.csv) files containing the processed event data and a summarized view of the data that includes start and end times for each event.



Source: Battelle

Figure 3-43. Data Processing Flow

TRP Events Table Processing

The data elements found in Table 3-6 contain the device, trip and timestamp elements that align with the same fields in the UMTRI DAS data set. Including these fields enable joining of the TRP event data with other DAS data sets.

Table 3-6. TRP Events Data Elements

Element Name	Type	Source	Definition
Device	Int PK	Programmed into the miniWSU	Device Identifier (Safety Pilot assigned ID for the device/vehicle combination)
Trip	Int PK	From DAS time subset data. Populated during Battelle's DAS synching process	DAS Trip Identifier for linking to the DAS data
Time	Int PK	From DAS time subset data. Populated during Battelle's DAS synching process	DAS Timestamp since last ignition in 1/100 seconds for linking to the DAS data
GPSTimeWSU	bigint	From miniWSU's GPS location data	GPS timestamp from WSU in epoch format
TRPTrip	int	Incrementing integer from the miniWSU. This number increases each time power is applied to the unit	Trip Identifier from the WSU (not the same as DAS)
TRPDate	int	miniWSU date from its internal clock in UTC format	Date from WSU (MMDDYY) UTC
TRPTime	real	miniWSU time from its internal clock in UTC format	Time from WSU (HHMMSS.S) UTC
TRPAlertType	Nvarchar (50)	Generated from the TRP application on the IVD. This is created when a new alert or warning is displayed on the in vehicle device	Enumeration consisting of Application (PED, RTV, etc.) and Alert Level (WARNING, ALERT)[6]
Latitude	float	From miniWSU's GPS location data	Vehicle Position, Latitude (decimal degrees)
Longitude	float	From miniWSU's GPS location data	Vehicle Position, Longitude (decimal degrees)
Message	Nvarchar (255)	Generated from the TRP application on the IVD. This is created when a new cautionary or warning alert is displayed on the in vehicle device, and is a human readable log message explaining the alert or warning displayed	Event Message
Heading	real	From miniWSU's GPS location data	Vehicle Heading (decimal degrees from true north)
Speed	real	From miniWSU's GPS location data	Speed of the vehicle, (meters/sec)
UMTRIEventType	int	UMTRI Event Type defined in	UMTRI encoded event level

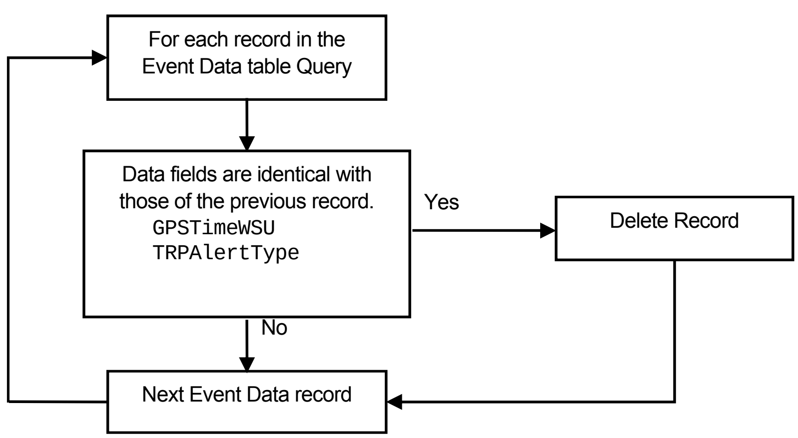
Source: Battelle

[6] Terminology for Alert Types and Levels evolved over the course of the project. Enumerations shown here are the original terminology as found in the actual data.

The DAS data elements are provided by the DAS database and are merged into the Event Data table using a SQL join based on the Device Identifier field and the GPS Timestamp field using the following SQL query.

```
SELECT [TRP].[dbo].[EventData].[DeviceID] AS [Device],
       [DAS].[dbo].[RawWsu].[Trip],
       [DAS].[dbo].[RawWsu].[TimeCs] AS [Time],
       [TRP].[dbo].[EventData].[GPSTimeWSU],
       [TRP].[dbo].[EventData].[TripID] AS [TRPTrip],
       [TRP].[dbo].[EventData].[Date] AS [TRPDate],
       [TRP].[dbo].[EventData].[Time] AS [TRPTime],
       [TRP].[dbo].[EventData].[TRPAlertType],
       [TRP].[dbo].[EventData].[Latitude],
       [TRP].[dbo].[EventData].[Longitude],
       [TRP].[dbo].[EventData].[Message],
       [TRP].[dbo].[EventData].[Heading],
       [TRP].[dbo].[EventData].[Speed],
       [TRP].[dbo].[EventData].[UMTRIEventType]
FROM [TRP].[dbo].[EventData] LEFT OUTER JOIN
     [DAS].[dbo].[RawWsu] ON [TRP].[dbo].[EventData].[GPSTimeWSU] =
     [DAS].[dbo].[RawWsu].[GPSTimeWSU] AND
     [TRP].[dbo].[EventData].[DeviceID] = [DAS].[dbo].[RawWsu].[Device]
ORDER BY [TRP].[dbo].[EventData].[DeviceID],
         [TRP].[dbo].[EventData].[GPSTimeWSU],
         [DAS].[dbo].[RawWsu].[TimeCs]
```

This linking process between the TRP IVD data and the DAS data can create some duplicate records due to an occasional disparity between the DAS time field and the GPS timestamp; where several DAS time increments may pass without the GPS timestamp incrementing in synchrony. In this event, the duplicate records are deleted using the logical flow diagram shown in Figure 44, leaving only first occurrence of the record.



Source: Battelle

Figure 3-44. Eliminate Duplicate Records Flow Diagram

TRP Event Summary Table Processing

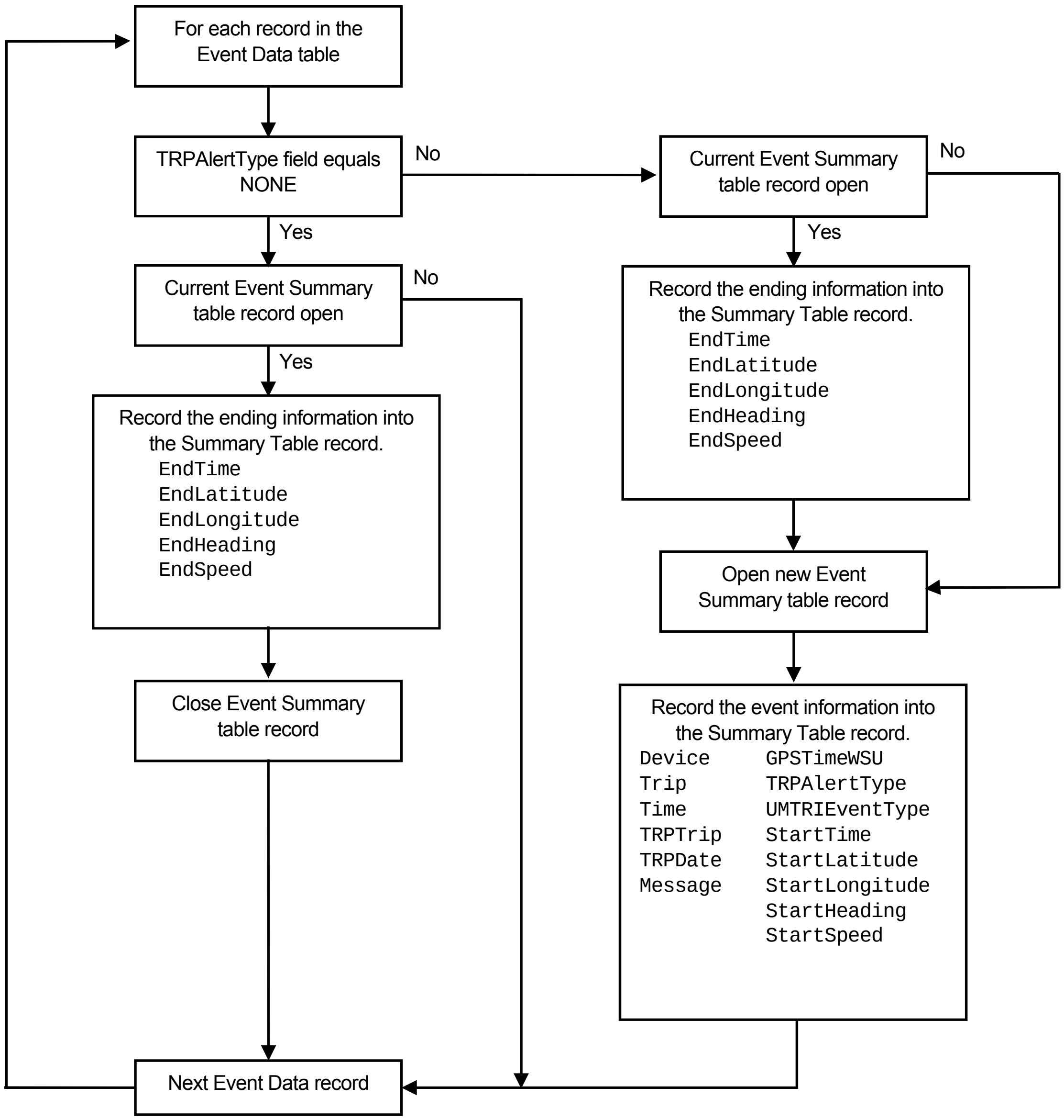
The TRP Event Summary Data table provides a summary of the data in the TRP Events Data table, as shown in Table 3-7. The event summary is produced by identifying the beginning and ending records for each event occurrence and combining the records together to create a single cohesive record describing the event. An event begins when a record in the Event Data table is found that has a TRP alert type other than NONE, and ends with the next chronological event record. If the next event record begins a new event, then its start information will be shared in common with the ending information of the previous event. A logical flow diagram of the event summary compile process is shown in Figure 3-45.

Table 3-7. TRP Event Summary Data Elements

Element Name	Type	Definition
Device	Int PK	Device Identifier (Safety Pilot assigned ID for the device/vehicle combination)
Trip	Int PK	DAS Trip Identifier for linking to the DAS data
Time	Int PK	DAS Timestamp since last ignition in 1/100 seconds for linking to the DAS data
GPSTimeWSU	bigint	GPS timestamp from WSU in epoch format. Represents the timestamp for the start of the event
StartTime	real	Start Time of the event from DAS data in 1/100 seconds since last ignition
EndTime	real	End Time of the event from DAS data in 1/100 seconds since last ignition
TRPTrip	int	Trip Identifier from the WSU (not the same as DAS)
TRPDate	int	Date from WSU (MMDDYY) UTC
TRPAlertType	Nvarchar (50)	Enumeration consisting of Application (PED, RTV, etc.) and Alert Level (WARNING, ALERT)[7]
UMTRIEventType	Int	UMTRI encoded event level
Message	nvarchar (255)	Event Message
StartLatitude	float	Vehicle Position at Start Time, Latitude (decimal degrees)
StartLongitude	float	Vehicle Position as Start Time, Longitude (decimal degrees)
StartHeading	real	Vehicle Heading at start time (decimal degrees from true north)
StartSpeed	real	Speed of the vehicle at start time (meters/sec)
EndLatitude	float	Vehicle Position at End Time, Latitude (decimal degrees)
EndLongitude	float	Vehicle Position at End Time, Longitude (decimal degrees)
EndHeading	real	Vehicle Heading at end time (decimal degrees from true north)
EndSpeed	real	Speed of the vehicle at end time (meters/sec)

Source: Battelle

[7] Terminology for Alert Types and Levels evolved over the course of the project. Enumerations shown here are the original terminology as found in the actual data.



Source: Battelle

Figure 3-45. Event Summary Flow Diagram

Data Summary

Analysis of bus data in terms of TRP performance assessment is the subject of the TRP Refinements section of this report. This section provides a summary of data collected and delivered to US DOT.

Original Deployment

During the period from February 2013 through September 2013, 23,211 events were captured by the TRP IVD, of which 1,995 were Warnings and 1,720 were Cautions (Informs). A breakdown of these events is provided below in Table 3-8. The eight referenced monthly data reports covering the original deployment period provide additional details on the data processing and data files delivered.

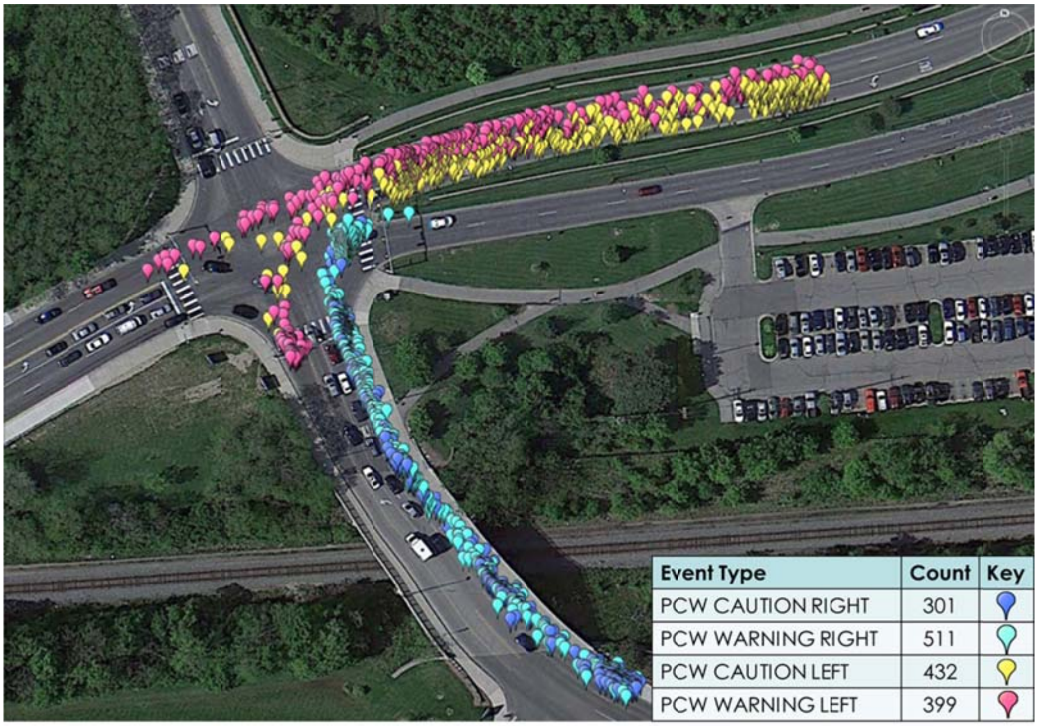
Table 3-8. Original Deployment Event Summary

Bus	3046	3047	3045	
Device ID	17101	17102	17103	Total
Calendar Days	145	154	138	437
Ignition Cycles	381	280	272	933
EEBL Left Caution	3	2	1	6
EEBL Right Caution	5		4	9
EEBL Warning	4	1	5	10
CSW Right Caution	4	12	7	23
CSW Right Warning	28	99	41	168
CSW Left Caution			1	1
CSW Left Warning	74	66	78	218
FCW Caution	415	123	343	881
FCW Warning	286	114	267	667
PCW Left Caution	155	121	156	432
PCW Right Caution	151	119	31	301
PCW Intersection (No Alert)[8]	1279	1220	1244	3743
PCW Left Warning	101	113	185	399
PCW Right Warning	295	160	56	511
RTVW Caution	39	17	11	67
RTVW None (No Alert)[9]	6374	5271	4108	15753
RTVW Warning	11	6	5	22
Total	9224	7444	6543	23211
All Warnings	799	559	637	1995
All Cautions	772	394	554	1720

Source: Battelle

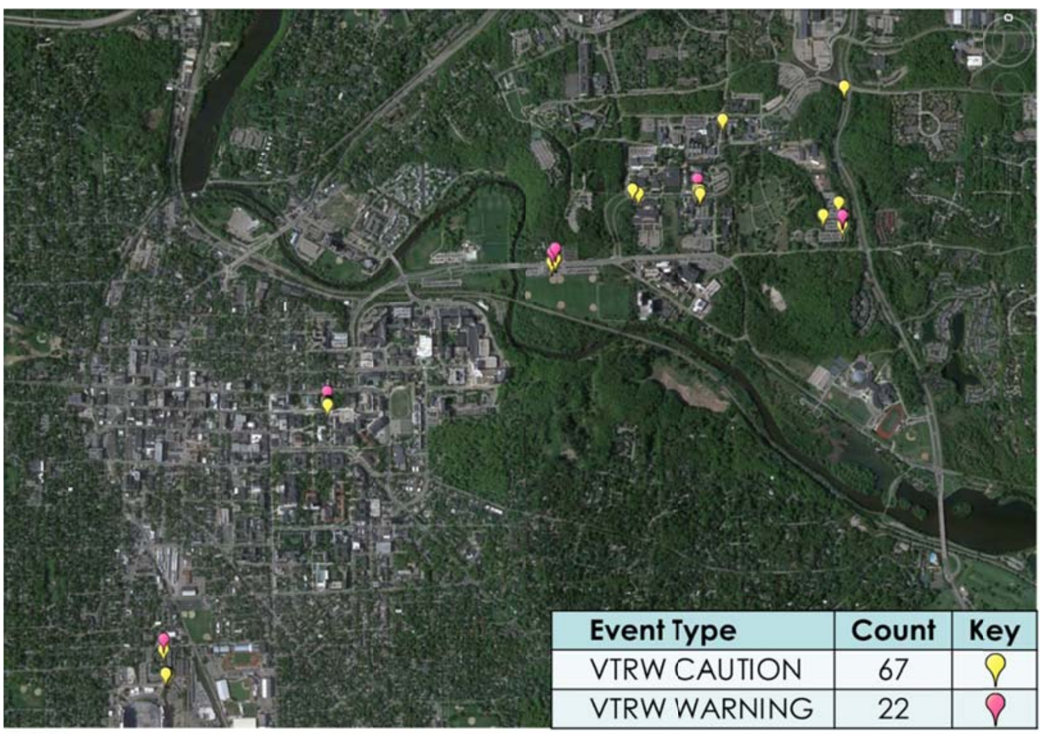
For the original deployment, Figure 3-46 shows the PCW Caution and Warning events plotted on a map, while Figure 3-47 shows the VTRW Caution and Warning events. The points shown are the starting points for each event as recorded by the IVD.

[8] PCW Intersection is the event type that indicates the PCW application is active (bus is in the turn lane) without an Alert condition (no Pedestrian in crosswalk and crosswalk call button not pressed).
[9] VTRW None is the event type that indicates the VTRW application is active (bus is at bus stop) without an Alert condition (no remote vehicle threat or no bus driver intent-to-proceed).



Source: Battelle, Google Inc.

Figure 3-46. Original Deployment PCW Event Map



Source: Battelle, Google Inc.

Figure 3-47. Original Deployment VTRW Event Map

Redeployment

During February/March 2014 (February 10 – March 11), 4,730 events were captured by the TRP IVD, of which 294 were Warnings and 262 were Cautions (Informs). A breakdown of these events is provided below in Table 3-9. The referenced report, Data Delivery – February/March 2014 Redeployment, provides additional details on the data processing and data files delivered for this period.

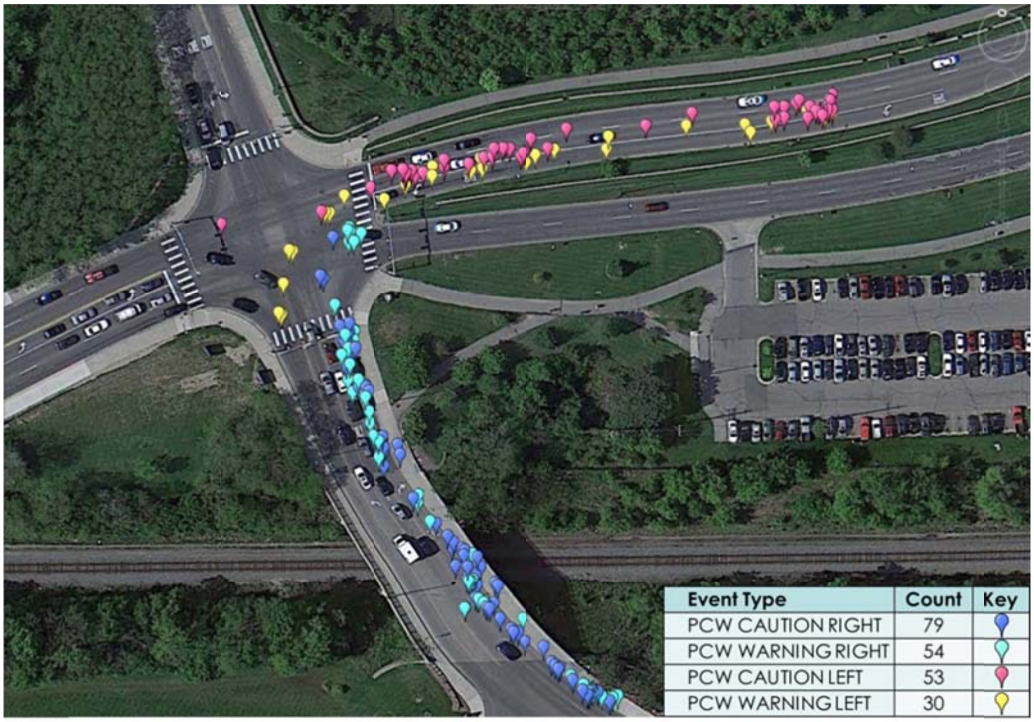
Table 3-9. Redeployment Event Summary

Bus	3046	3047	3045	
Device ID	17101	17102	17103	Total
Calendar Days	19	18	21	58
Ignition Cycles	35	25	34	94
EEBL Left Caution	1			1
EEBL Right Caution			2	2
EEBL Warning	1			1
CSW Right Caution				0
CSW Right Warning	3	2		5
CSW Left Caution				0
CSW Left Warning	26	45	15	86
FCW Caution	65	15	40	120
FCW Warning	69	17	29	115
PCW Left Caution	12	18	23	53
PCW Right Caution	9	29	41	79
PCW Intersection (No Alert)[10]	129	139	242	510
PCW Left Warning	10	8	12	30
PCW Right Warning	7	12	35	54
RTVW Caution	1	1	5	7
RTVW None (No Alert)[11]	954	1261	1449	3664
RTVW Warning		1	2	3
Total	1287	1548	1895	4730
All Warnings	116	85	93	294
All Cautions	88	63	111	262

Source: Battelle

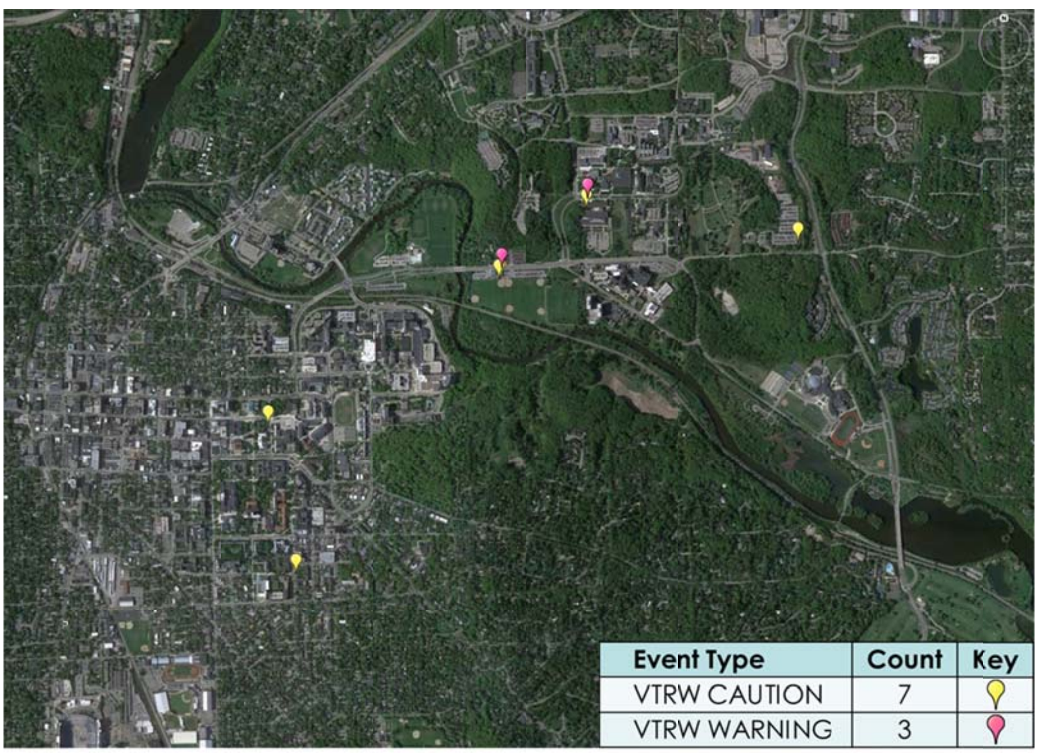
For the redeployment, Figure 3-48 shows the PCW Caution and Warning events plotted on a map, while Figure 3-49 shows the VTRW Caution and Warning events. The points shown are the starting points for each event as recorded by the IVD.

[10] PCW Intersection is the event type that indicates the PCW application is active (bus is in the turn lane) without an Alert condition (no Pedestrian in crosswalk and crosswalk call button not pressed).
[11] VTRW None is the event type that indicates the VTRW application is active (bus is at bus stop) without an Alert condition (no remote vehicle threat or no bus driver intent-to-proceed).



Source: Battelle, Google Inc.

Figure 3-48. Redeployment PCW Event Map



Source: Battelle, Google Inc.

Figure 3-49. Redeployment VTRW Event Map

Driver Feedback

Original Deployment – Driver Survey

Battelle developed the TRP Bus Operator Survey Questionnaire, in coordination with USDOT, the Volpe IE, and the Test Conductor (UMTRI). The Test Conductor administered the survey in August-September 2013, and provided the 50 questionnaire responses to Volpe. The Volpe IE performed analysis and provided results in the form of a briefing entitled, "Transit Driver Acceptance Preliminary Results", in November 2013 (the results from the complete IE analysis will be provided by the end of calendar year 2014, and be publically available). Assessment of nineteen out of eighty-three driver survey questions was included. A summary of the most significant results is provided in Table 3-10.

Table 3-10. Driver Survey Summary, Original Deployment

Survey Subject	Significant Results
Liked least	Perceived false positives
Difficulties	Perceived false positives (particularly PCW); system down
Increased driving safety	Generally disagree
Easy to understand	Screens shown too briefly (particularly FCW and EEBL)
PCW	False positives from vehicles detected in crosswalk; False positives for bus in wrong lane
VTRW	Want it to warn of cars to left of bus at any time
Suggested changes	Make it talk; make it accurate

Source: Battelle

Original Deployment – Driver Focus Group

A focus group of transit operators that drove the TRP-equipped buses during the original deployment period was held on September 30, 2013, at UMTRI facilities. The objective of the focus group was to obtain opinions from the transit operators on the understandability, usability, perceived safety benefits, and desirability of the TRP applications. The focus group material was developed by Battelle while the focus group was conducted by the Test Conductor (UMTRI). The focus group was observed live by Battelle representatives, via a video and audio feed in a separate room.

Out of the roughly 90 transit operators that drove TRP-equipped buses during the deployment period, five operators were targeted by UMTRI as primary potential participants for the focus group. These five operators represented those operators that drove the majority of hours in the TRP-equipped buses (70% of the total hours were driven by these five operators). Operators falling into the remainder of the top twenty with regards to driving hours also were asked to participate. Ultimately, seven operators agreed to participate in the focus group; however, only five of them attended it. The participating operators included the top two drivers, as well as numbers 5, 6, and 19 in the overall ranking of hours driven. Their combined percentage was 46% of total hours driven. Two of the participants were primarily day-shift operators, two were primarily evening-shift operators, and one drove a mixture of shifts.

All participants were active to some degree during the discussions; however, there was a clear distinction in their participation levels. In general, two of the participants were the main talkers during the focus group, two were moderate talkers, and one responded pretty much only when he was directly asked for his opinion. Interestingly, these behaviors directly correlated with the hours-driven rankings – the top two operators were the most talkative ones, numbers 5 and 6 were the moderate talkers, and number 19 was the least talkative.

The focus group was completed within the scheduled two hours. Participants were paid a $100 cash incentive at the beginning of the focus group. The UMTRI facilitator had a good rapport with the operators, because he served as the liaison between the TRP technical team and the transit operators throughout the deployment. This relationship likely helped the operators to feel at ease and be willing to express their comments openly during the focus group.

In-Vehicle Display (IVD)

From a usability standpoint, the general consensus was that the IVD should be located more in front of the driver so that he/she does not need to look over to the side to view cautions and warnings. Another suggestion was that the cautions and warnings need to be displayed longer on the screen. Related to this suggestion, one participant thought that it would be better to have a blank screen as opposed to the "green bus" default screen when no caution or warning is being displayed (i.e., a caution/warning flashing onto the blank screen would be more eye-catching). There was a mixture of opinions on whether the audio beeps were helpful or annoying. One suggestion was to have the system issue verbal warnings (e.g., "pedestrian in crosswalk") instead of beeps. This manner of audio notification would reduce the need for the operator to look at the IVD.

Pedestrian in Crosswalk Warning (PCW)

Only two of five operators from the focus group drove the routes where PCW cautions and warnings would be activated (i.e., making turns at the intersection). The others drove through those intersections in different lanes (i.e., different bus routes), thus would have seen only the "PCW ready" screens as they approached the intersections. It was not clear whether the distinction between PCW cautions and warnings was obvious to the operators. One issue expressed by some of the operators is that pedestrians do not always press the "walk" button.

False positives were a significant problem with this application at the beginning of the deployment, but improvement was seen by the operators as the deployment progressed. The buses themselves still seem to cause some of the false positives (i.e., the rear of the bus passing through the intersection trips the warning). One operator stated that he had seen false negatives (i.e., pedestrian in crosswalk, but no warning issued), which could have several causes – not limited to roadside equipment failure, on-board equipment failure, or inaccurate lane tracking due to GPS limitations.

Bicyclists are a big problem at the intersection where PCW is deployed. It was felt that the bicyclists are moving too fast for the detectors to sense and respond that bicyclists have entered the intersection (one operator theorized that the same might be true for runners). These bicyclists are seen as a much more safety hazard than pedestrians, because they are not easily seen by bus operators as they quickly enter the intersection. As a result, PCW is not seen as a significant benefit because it is not capable of warning about the main problem (i.e., bicyclists). However, one operator felt that PCW was the best feature of TRP.

Vehicle Turning Right Warning (VTRW)

Vehicles pulling out from behind buses are a common problem witnessed by all of the participants. One operator stated that VTRW is the "most important issue that engineers could focus on" and that there would be a "1000% improvement if it could be solved." All participants felt that the VTRW caution was far more important than the warning, because it is crucial to know that a vehicle has pulled out from behind the bus and possibly entered the operator's blind side so that there is more time to react to what the vehicle may do.

None of the operators in the first focus group actually received a VTRW warning. The "VTRW ready" screen seemed to work as intended, but some operators felt that it often stayed on too long after the bus left the bus stop. One operator felt that VTRW was the best application, but he still does not want it installed on all buses until it is improved to catch vehicles pulling out from behind the bus.

Redeployment – Driver Focus Group

A focus group of TRP-equipped bus drivers for the redeployment period was conducted on March 18, 2014, at UMTRI. The objective of the focus group was to obtain opinions on the revisions made to the TRP system, as well as the understandability, usability, perceived safety benefits, and desirability of the TRP applications. The focus group material was developed by Battelle (based on the original focus group material) while the focus group was conducted by the Test Conductor (UMTRI). The focus group was observed via video and audio feed in a separate room by Battelle.

Out of the roughly 30 drivers that drove TRP-equipped buses during the redeployment period, three drivers participated in the focus group, including the top two drivers, as well as the fifth highest in the overall ranking of hours driven. Their combined percentage was 44% of total hours driven. Two operators were participants in the September 2013 focus group, while the third one did not drive a TRP-equipped bus during the first deployment. One driver drove the Commuter routes five days per week using bus #3045, one drove the Northwood route five days per week using bus #3046, and one drove the Commuter routes two evenings per week and the Northwood route three evenings per week primarily using bus #3045 but sometimes using bus #3046. Note the Commuter routes are the ones that turned through the intersection with the Pedestrian Crosswalk Warning, while the Northwood route continued through that intersection without a turn.

The most significant results from the driver focus group for the redeployment are summarized in Table 3-11. The Transit Operator Focus Group II Summary report provides additional details. The subject TRP revisions are explained in the TRP Refinements section of this report.

Table 3-11. Driver Focus Group Summary, Redeployment

Subject	Significant Results
Adjusted IVD position within driver area	Drivers' consensus was that the new position for the IVD was good.
Lengthened time that cautions/warnings are displayed	Drivers noticed the increased time that the cautions and warnings were displayed and found that to be helpful.
Replaced beeps with verbalized cautions/warnings	The driver of bus #3046 had no problems understanding the verbalized cautions and warnings; however, both drivers of bus #3045 could not understand the words (they could hear sounds coming from the IVD, but could not hear them clearly over the other sounds in the bus [e.g., fans running]). The bus #3046 driver indicated that hearing the audible message triggered him to look at the display to confirm what he heard and that the verbalized caution/warning gives the driver a good idea of what to look for and was an improvement over the beeps previously used. Hypothetically (because they did not hear the words clearly), the other drivers agreed with this opinion.
Replaced IVD power cables (if damaged) to ensure IVDs are properly powered	The driver new to TRP claimed that his IVD was unpowered (not "on") approximately half the time, while the other drivers (not new) experienced this problem only once between them. It is unknown why the IVDs were not "on", though it was determined not to be the result of damaged power cables.
Adjusted pedestrian detectors to decrease false pedestrian warnings caused by vehicles in crosswalk	One driver observed that he still receives some false positives, but that the number of them was a "whole lot better" than during the first deployment. None of the drivers completely believed the cautions/warnings without confirming for themselves that there was a pedestrian in or near the crosswalk.
PCW application not activated when bus is in the pass-through lanes on Fuller (i.e., not turning south on Medical Center)	The bus #3045 driver on the Northwood route indicated that he always got the PCW Ready screen when in the pass-through lane at that intersection, while the bus #3046 driver got that screen only some of the time. No pattern for this behavior (e.g., hitting the intersection on a green light versus having to stop for a red light) could be identified.
PCW application deactivated once center of bus has passed through the crosswalk	All drivers said that the PCW Ready screen or caution/warning was deactivated as they drove through the crosswalk. The drivers believed that the timing of the cautions/warnings was adequate.
Removed VTRW caution/warning when gear position is not in forward drive	Discussions on VTRW were brief because none of the drivers actually received a VTRW warning. The "VTRW ready" screen seemed to work as intended, though.
Overall benefit	None of the drivers believed that the TRP system provided them any real benefit. They already were aware of situations that triggered the cautions and warnings before they received them, and often times would watch or listen for the caution/warning to see if it would be provided. One driver thought that TRP might have some benefit for inexperienced drivers. Another driver could see its potential usefulness in a large city (e.g., Chicago) with more traffic and aggressive drivers.
Desirability	In general, the participants had no real desire to see TRP utilized on the entire bus fleet as the applications currently are implemented. It seemed that this viewpoint was based on a feeling that no significant benefits are being provided at this point in time.

Source: Battelle

TRP Refinements

This section provides a summary of TRP deployment analysis, lessons learned, and TRP system refinements (revisions) that were developed and fielded for the February/March 2014 redeployment. Also included are the results of redeployment analysis with comparison to the original deployment. This section is based on the following reports that were generated under this contract:

- Proposed TRP and Applications Revisions Report
- Summary of Safety Applications Test Report

The TRP Device and Safety Applications section of this report describes the final TRP configuration inclusive of the refinements presented in this section. This section describes the specific changes from the original deployment and why the changes were made.

Battelle analysis and refinements focused on the two Battelle-developed Transit-Specific Safety Applications, PCW and VTRW, since the three Basic Safety Applications extend beyond the TRP project and are outside of Battelle's role and control to revise.

Original Deployment Analysis

Pedestrian in Crosswalk

Battelle analyzed one-hundred-sixty (160) PCW Warnings from the original deployment, the same sampling as originally analyzed by the Volpe IE.

Valid alerts were determined by the presence of a pedestrian in one of the two application-supported crosswalks and the bus being on the path that traverses through the crosswalk. Battelle used DAS bus video to determine bus path, supplemented by GPS data. Battelle also used bus video to determine Pedestrian presence in the crosswalk.

Invalid alerts were determined by conclusive video evidence that a pedestrian was not present in the crosswalk or the bus wasn't on the path that traversed through the crosswalk (or both).

Alerts categorized as Unsure were due to the video being too grainy, too dark, or too far away to allow presence of a pedestrian in the crosswalk to be conclusively determined. Bus path was determined in all cases by either GPS or video analysis, thus no alerts of unsure validity were the result of unsure bus path.

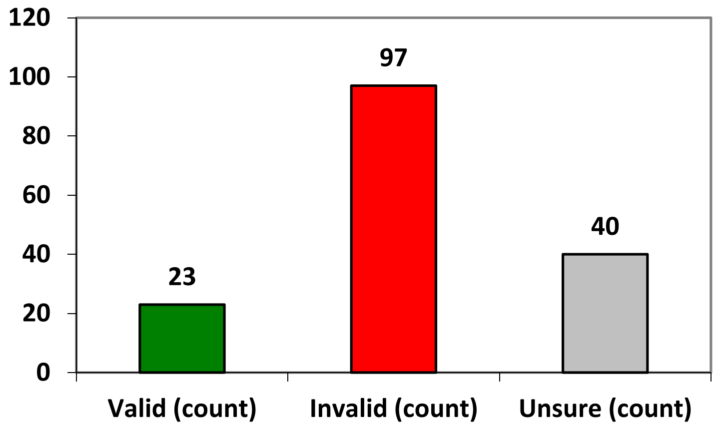
Table 3-12 provides a PCW Warning Validity Matrix, based on the criteria described above.

Table 3-12. PCW Warning Validity Matrix

Bus Path	Validity If Pedestrian In Crosswalk	Validity If Pedestrian Not In Crosswalk	Validity If Unsure Pedestrian In Crosswalk
Bus Path Through Crosswalk	Valid	Invalid	Unsure
Bus Path Not Through Crosswalk	Invalid	Invalid	Invalid
Unsure If Bus Path Through Crosswalk	Unsure	Invalid	Unsure

Source: Battelle

Figure 3-50, PCW Warning Analysis Results, shows the breakdown of Valid, Invalid, and Unsure PCW Warnings based on Battelle analysis.



Source: Battelle

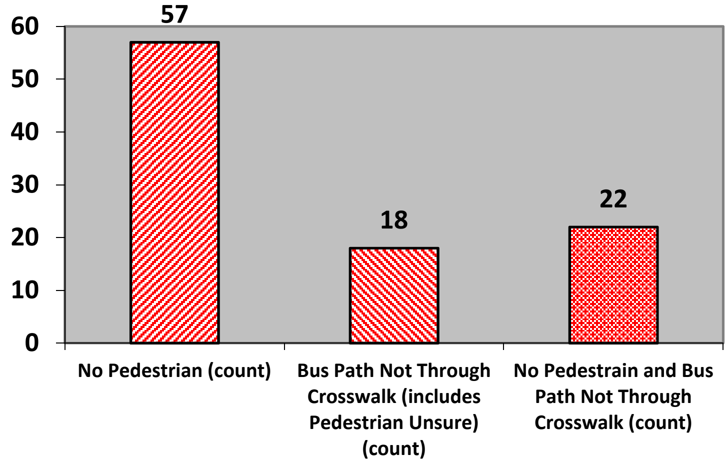
Figure 3-50. PCW Warning Analysis Results

A breakdown of the Invalid alerts is provided in Figure 3-51, PCW Invalid Analysis Results. As shown in the figure, the majority of invalid PCW alerts were caused by no pedestrian in the crosswalk. Based on video review, the cause for these "false positive" alerts was that the pedestrian motion detectors were detecting a vehicle in the crosswalk – either the tail end of the host bus, or another slow moving vehicle. This occurred due to the vehicle having a velocity component in the direction of the crosswalk (perpendicular to the road) less than the threshold velocity of 7 miles per hour (MPH) (in the direction of the crosswalk) of the motion detectors.

The other cause – bus path not through the crosswalk – occurred because the PCW algorithm projected the bus path to be through the crosswalk when in fact the bus was not in the turn lane and traveled straight through the intersection. This could occur for either of two reasons: 1) the bus lane determined by GPS was the turn lane when in fact the bus was in the straight lane, or 2) the GPS and actual location were the straight lane, which happened because of a design decision that attempted to be tolerant of GPS inaccuracies by enabling alerts when the bus was in fact in the turn lane but GPS was reporting the bus was one lane over.

Some warnings had no pedestrian in the crosswalk and the bus traveled straight through the intersection, in which case it was invalid for both reasons with the event being triggered by another vehicle in the crosswalk.

Note that the bus distance that the PCW application was enabled to display alerts on exit from the intersection was not specified as a requirement. The design decision was that the PCW application was enabled while the GPS location of the bus was within 28 meters of the center of the intersection. Alerts occurring in accordance with this design were categorized as valid. Since 28 meters proved to be too far from a usefulness and nuisance perspective, this was addressed as a Lesson Learned.



Source: Battelle

Figure 3-51. PCW Invalid Analysis Results

Battelle concluded there were three main root causes which resulted in invalid PCW alerts:

- Crosswalk detectors cannot accurately distinguish pedestrians from vehicles
- Application settings allow alerts in Lane 7 (see Figure 3-52) on Fuller Avenue
- GPS position indicates incorrect lane

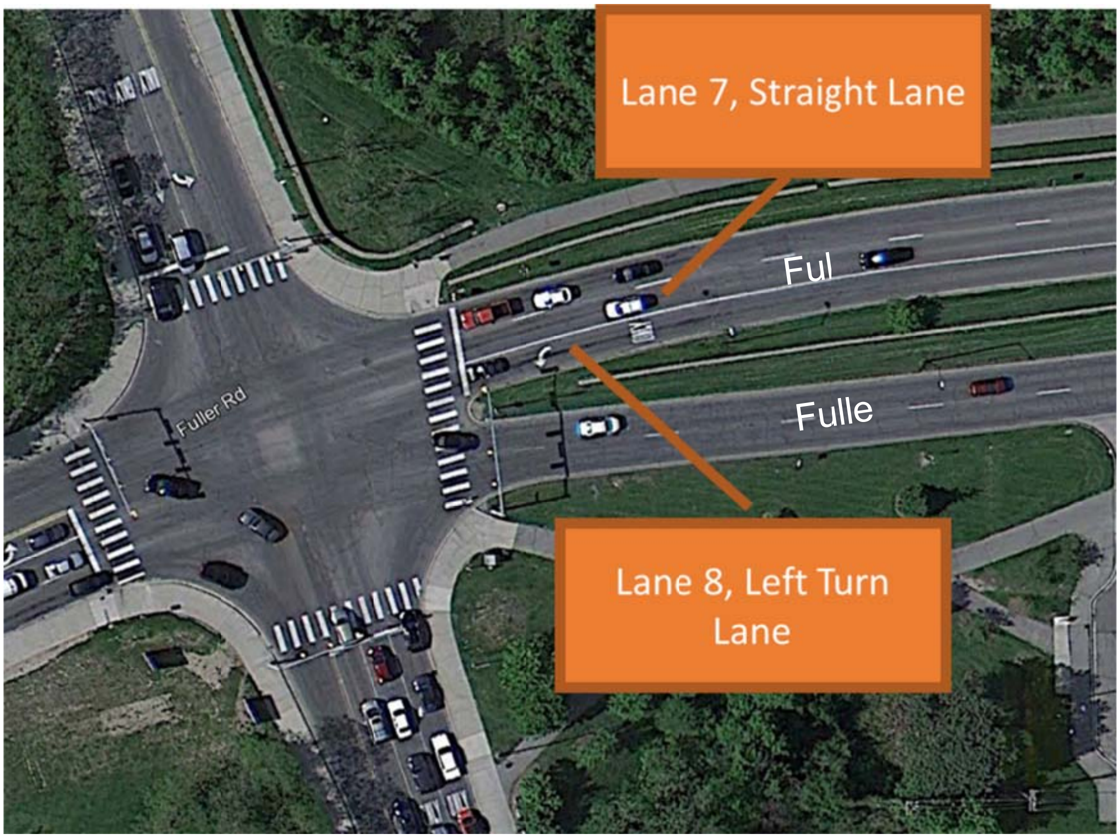
Crosswalk Detectors Cannot Accurately Distinguish Pedestrians from Vehicles

Inability of the crosswalk detectors to accurately distinguish pedestrians from vehicles was the most common cause of false positive PCW warnings. Prior to live testing, the detectors were modified to ignore objects moving faster than 7 MPH (velocity component in direction of the crosswalk) and to ignore objects if detected for less than a verification period of approximately 2.5 seconds. Even though this reduced the likelihood of false positives, false warnings sometimes occurred when the host bus traveled through the crosswalk at slow speeds at an angle other than perpendicular to the crosswalk. This was seen more frequently on the right turn from Medical Center Drive to Fuller Avenue than on the left turn from Fuller Avenue to Medical Center Drive. Vehicles other than the host bus travelling through the crosswalk at slow speeds were also found to be identified by the detectors as pedestrians. There are no known cases where the detectors provided a false trigger for a reason other than a slow moving vehicle in the crosswalk.

Application Settings Allow Alerts in Lane 7 on Fuller Avenue

Battelle discovered that the lane detection used for displaying the pedestrian alerts was inaccurate due to GPS error. In some cases the GPS position would be north of the actual lane, while in other cases south of the actual lane. The GPS error was found to be as great as 10 meters. The actual lane width is approximately 3.35 meters, thus any reported position more than 1.675 meters different from the actual position is outside of the actual lane.

It was assumed the TRP buses would operate exclusively on the Commuter North and Commuter South loops, always making the prescribed turns at the PCW-enabled intersection. To avoid missed alerts due to GPS inaccuracies, a setting in the software was included to enable alerts if the GPS position was in Lane 7 (the leftmost straight lane) as well as Lane 8 (the left turn lane). During deployment, the TRP buses did not exclusively operate on the Commuter North and Commuter South loops, thus violating the assumption. This allowed for alerts to occur when the bus actually travelled straight through the intersection, consistent with the GPS-reported position. Figure 3-52 shows the subject lanes on Fuller Avenue at the Medical Center Drive intersection.



Source: Battelle, Google Inc.

Figure 3-52. Fuller Avenue Lanes

GPS Position is Incorrect Lane

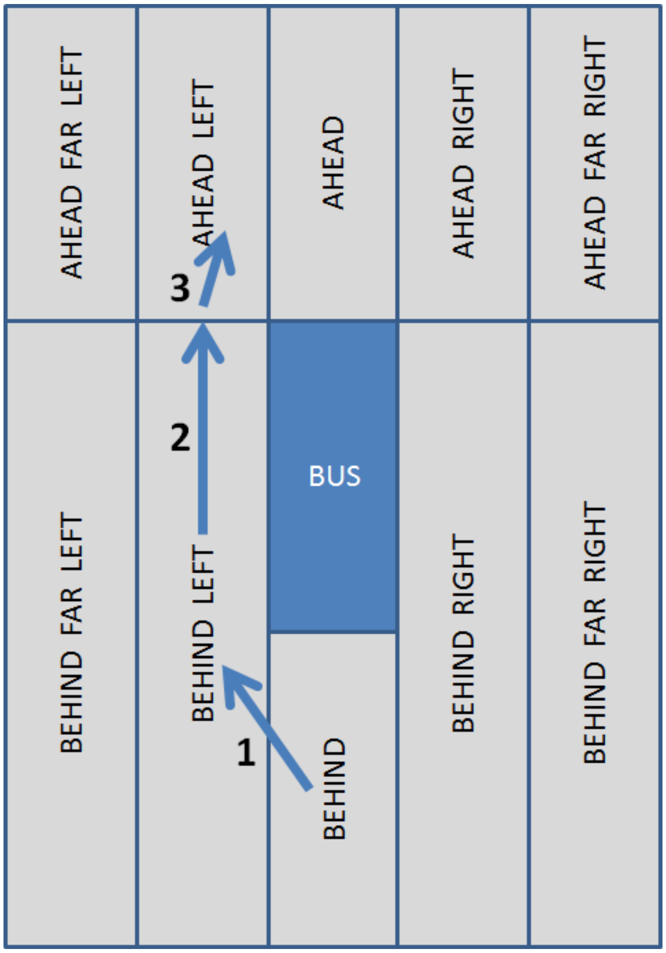
As a direct result of GPS error, the buses could actually be located a lane over from the GPS-reported position, thus enabling alerts when the buses were a lane over from the enabled lanes. Based on inaccurate GPS position, the TRP system determined buses were in the turn lane (or in Lane 7 on Fuller Avenue) when in fact they were not, thus enabling alerts and resulting in false positive warnings when a pedestrian was detected in the crosswalk.

Vehicle Turning Right in Front of Bus

Battelle analyzed forty-three (43) VTRW Alerts (cautions and warnings) from the original deployment, the same sampling as originally analyzed by the Volpe IE. Battelle leveraged the Volpe IE analysis and performed additional analysis using DAS video and IVD data.

Valid alerts were determined by the Remote Vehicle (RV) following the prescribed path relative to the Host Vehicle (HV) at an application-supported bus stop and the HV Brake Pedal not being depressed. The Brake Pedal was the sole factor in determining the bus driver's "intent to proceed" for the original deployment. Waiting for the bus to move forward was decided to be too late for an alert to be issued for safety purposes.

The RV prescribed path to generate a cautionary alert is from Behind, to Behind Left, as shown in Figure 3-53. The prescribed path to generate a warning is from Behind, to Behind Left, to Ahead Left, followed by a 5.5% turn into the direction of the HV. The relative position of the RV to the HV (Behind, Behind Left, Ahead Left, etc.) is termed the Target Classification, and is calculated based on the contents of the RV and HV BSMs.



Source: Battelle

Figure 3-53. VTRW Target Classification

Invalid alerts were determined by evidence that the RV did not follow the prescribed path relative to the HV or the HV Brake Pedal was depressed (or both).

Alerts categorized as Unsure were due to lack of evidence to make a conclusive determination of the RV path relative to the HV. Brake Pedal status was determined in all cases (never Unsure), and furthermore was always Not Depressed (no Invalids due to Brake Pedal depressed).

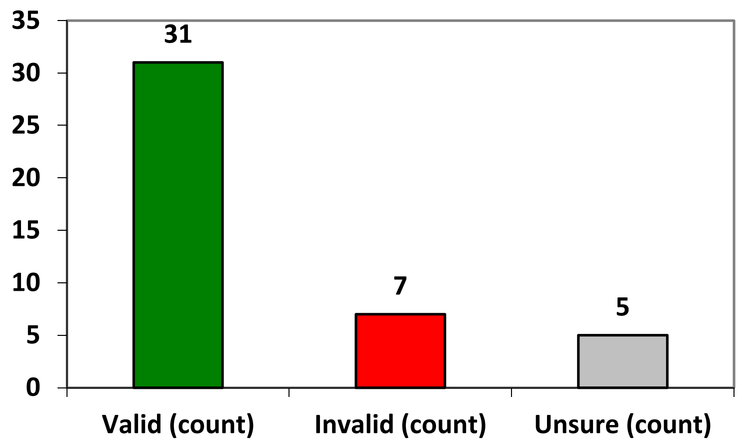
Table 3-13 provides a VTRW Alert Validity Matrix, based on the criteria described above.

Table 3-13. VTRW Alert Validity Matrix

Brake Pedal Position	Validity If RV Follows Prescribed Path	Validity If RV Doesn't Follow Prescribed Path	Validity If Unsure RV Follows Prescribed Path
Brake Pedal Not Depressed	Valid	Invalid	Unsure
Brake Pedal Depressed	Invalid	Invalid	Invalid
Unsure If Brake Pedal Depressed	Unsure	Invalid	Unsure

Source: Battelle

Figure 3-54, VTRW Alert Analysis Results, shows the breakdown of Valid, Invalid, and Unsure VTRW Alerts based on Battelle analysis (cautions and warning are grouped together).



Source: Battelle

Figure 3-54. VTRW Alert Analysis Results

All seven Invalid alerts were due to the RV not following the prescribed path relative to the HV.

Battelle concluded there was one main root cause which resulted in invalid VTRW alerts:

- Incorrect Target Classification caused by GPS Error

Incorrect Target Classification caused by GPS Error

Incorrect Target Classification was the direct cause for invalid VTRW alerts. The root cause was believed to be GPS accuracy as stated by DENSO.

Based on BSM inputs (including RV and HV GPS positions), the Target Classification algorithm at times incorrectly classified the relative target position causing invalid VTRW alerts. During Battelle's analysis, we found examples where the Target Classification of the RV was Behind, but video evidence showed the RV to actually be Behind Left. Once the RV passed the bus the Target Classification changed to Behind Left thus resulting in an invalid VTRW alert. These inconsistencies are assessed to be caused by error in GPS position – from the HV, RV, or both – which resulted in an incorrect relative position and target misclassification.

IVD vs. DAS Event Mismatch Investigation

It was observed that some warnings logged within the IVD database could not be fully synchronized with warnings logged within the DAS database. The problem was decomposed into two parts:

- Device-trip data from one source could not be matched with device-trip data from the other source.
- For Matched device-trips, there were DAS and TRP basic safety warnings that could not be synchronized.

An investigation revealed two primary root causes of the problem:

- An unexpected WSU reset was occurring that crippled the IVDs ability to properly record safety events.
- A damaged cable in bus 3046 was leading to persistent IVD battery depletion and shutdown.

In remedy of the WSU reset, the internal agent software within the WSU and the IVD software were modified to recover from WSU reset events. These actions are seen as a work-around with the long-term remedy being changes that would eliminate the WSU reset action[12].

The damaged power cable in bus 3046 was replaced and no further IVD battery depletion was observed. However, battery discharge was also observed on the other busses. During troubleshooting of this issue it was observed that aged IVDs at full brightness within their operational environment were barely able to maintain their charge.

Implemented Revision – WSU Reset Mitigations

During deployment, two changes to the TRP code were implemented.

1 The TRP Agent firmware was enhanced to detect and properly react to a WSU reset. Similar to the actions that it takes at startup, the TRP agent monitors the WSU task from the OS task list and detects changes in its presence or absence from that list. When the task goes from present to absent, it is determined that a WSU reset operation is occurring and the TRP agent will reenter its startup logic.

2 The IVD software was enhanced to record the local IVD epoch time within the event and position logs. The IVD time is set by the operator and a difference of 10 minutes has been observed between the IVD time and the GPS time. However, the difference between the IVD time and GPS time can now be calculated using the position log content and an adjustment is possible to calculate the GPS time of an event after a WSU reset.

Note that the first mitigation may obviate the second mitigation. The second mitigation was implemented on August 27, 2013 on all buses, and the first mitigation was implemented on September 17 on all buses. Data collected after these mitigations indicated that the impacts of the WSU resets were reduced to the approximate 20 second period when the reset was occurring.

[12] After the work-around changes, WSU resets lead to small intermittent windows of approximately 20 second duration where all transit safety applications are disabled while the WSU recovers.

Other Events during Deployment

There were "other events" throughout deployment that are not covered in the above sections. This section covers those events.

During deployment, issues with accuracy, availability, and the driver-vehicle interface were observed and addressed. Revisions for these issues were successfully fielded and tested during deployment. They are covered here for completeness.

- The CSW speed threshold was increased from 5 mph to 10 mph over the posted speed limit to reduce what were considered nuisance alerts.
- The IVD default screen was modified from predominantly white to predominantly black and a brightness control was added to address nighttime viewing issues (software change).
- An anti-glare protection screen was added to the IVD to improve sunlight readability.
- The DENSO mini-WSU firmware was updated to reduce the chance of power-up and/or power-down failure while in the presence of live CAN data.
- The IVD application software was corrected for the VTRW ready screen staying active beyond the geo-fenced bus stop zone.
- The IVD and wireless Ethernet router WiFi frequency was changed from 2.4 GHz to 5 GHz to resolve a third-order harmonic interference problem with the 800 MHz bus radio.

Lessons Learned

This section presents specific Lessons Learned based on the original deployment analysis.

Crosswalk Detector Accuracy is Insufficient for PCW Application

The pedestrian detector used by the TRP was the SmartWalk XP made by MS-SEDCO. It uses microprocessor-based Doppler microwave detection. The TRP sensor was configured to detect departing objects travelling at 7 MPH or less in the direction of the crosswalk. The sensor detection region is conic and the TRP sensors were centered on that part of the crosswalk that was within the expected bus pathway. The MS-SEDCO sensor was selected based on functional performance, availability, ease of installation and cost.

As discussed in the analysis section, inability of the crosswalk detectors to accurately distinguish pedestrians from vehicles was the most common cause of false positive PCW warnings. The MS-SEDCO detectors were modified prior to live testing to optimize their performance, though significant anomalies persisted during deployment. While some additional "tuning" of the detectors is expected to result in improvement, ultimately Battelle has concluded the MS-SEDCO detector accuracy is insufficient for this application.

TRP Application Logic Should be Independent of Actual Bus Route

The PCW application should not assume specific bus routes. The TRP buses did not exclusively run the Commuter North and Commuter South loops, and therefore did not always make the PCW-prescribed turns. The GPS reported position of Fuller Ave Lane 7 (straight lane) should be removed as enabling PCW alerts, since the assumed TRP bus routes proved to be false. Additionally, for proof of concept it is best to make algorithms more generic, thus better representing a future production system.

PCW Alerts should be Suppressed after Bus enters Crosswalk

PCW alerts remained enabled for display when a bus exited from the intersection while the bus GPS location was within 28 meters of the center of the intersection. Alerts could be displayed to the driver longer than needed, and sometimes alerts were generated after the bus completed the maneuver through the crosswalk. Such alerts were considered a nuisance and could be interpreted as false positives by the driver. The distance from the center of the intersection should be reduced.

GPS Accuracy is Insufficient for PCW and VTRW Applications

GPS locational inaccuracy was a root cause of VTRW target misclassifications and a defeating factor for PCW lane tracking. The WSU is equipped with a WAAS-enabled GPS receiver. This technology provides among the best locational accuracy that is generally and practically available in today's marketplace.

Although the WAAS specification requires a positional accuracy of better than 7.6 meters in both lateral and vertical measurements, vendor claims and actual measurements typically demonstrate a WAAS accuracy of 1.5 meters or better in both directions. A typical traffic lane is ~3.5 meters wide. The specified WAAS accuracy would be insufficient to support TRP needs. The measured and claim accuracy should support TRP needs. In practice, the WAAS-enable GPS supported TRP needs a majority of the time, but remained a source of TRP error.

Figure 3-55 below shows multiple bus locational traces through the instrumented PCW intersection at Fuller Avenue and Medical Center Drive. The bus traversed the intersection 14 times: 7 times turning left from westbound Fuller Avenue to southbound Medical Center Drive, and 7 times turning right from northbound Medical Center Drive to eastbound Fuller Avenue.

Source: Battelle, Google Inc.

Figure 3-55. Bus Traces at Fuller Avenue and Medical Center Drive

With the assumption that the actual bus location was within the intended lane and varied little between the individual traces, the GPS locational variation visually appears to be about the width of a lane. While this level of accuracy might be sufficient to support lane tracking to some degree, GPS locational variability due to differing weather conditions, foliage level, and time-of-day considerations will add to the variability demonstrated in the graphic. The locational accuracy of the WSU GPS receiver is insufficiently accurate to reliably support the TRP PCW and VTRW applications.

VTRW Alerts should be Suppressed when there is No "Intent to Proceed"

For the original deployment, only Brake Pedal status was used to determine the driver's "intent to proceed". Alerts displayed when the bus is in Park Gear or when the Parking Brake is applied are considered a nuisance and should be suppressed. While Parking Brake status from the CAN bus was determined to be unavailable, Gear Position should additionally be used as a basis to determine the driver's "intent to proceed".

Low Driver Acceptance caused by TRP Inaccuracies and IVD Weaknesses

TRP inaccuracies and IVD weaknesses were primary causes of low Driver Acceptance. Specific TRP inaccuracies are addressed under other lessons learned based on non-subjective data. Specific IVD weaknesses as perceived by the drivers are captured in the earlier Driver Feedback section.

Firmware/Software Reliability is Critical to System Performance

The WSU firmware can unexpectedly reset and cause a temporarily cessation of the TRP Alerts. The reliability of the WSU firmware and IVD software (code) is critical to system performance and perceived system effectiveness. Unreliable code can lead to system downtime, undermine operator confidence and lead to the defeat of the TRP mission as a whole. High quality, reliable, and robust code is required for TRP application success.

As an example of this need, the IVD vs. DAS Event Mismatch Investigation revealed that the WSU firmware was periodically resetting. A WSU reset is a planned response designed into the logic of WSU firmware. It can occur for the following reasons:

1 A crash of a WSU process.

2 A failure of a WSU process to meet a deadline due to CPU starvation.

3 A failure of a WSU process to obtain access to a shared resource such as hanging on a semaphore acquisition.

In each of these cases, a separate WSU monitor or watchdog process detects the condition, and then kills and restarts the core WSU processes that accomplish the WSU mission. Customized TRP firmware residing within the WSU (the TRP Agent) was designed with the assumption that the core WSU processes would persist throughout the duration of a device-trip. Consequently, the TRP Agent was left dysfunctional because it was incapable of accessing the shared memory that was newly defined because of the core WSU process restart. From the driver's perspective, the system would become dysfunctional, no longer displaying transit alerts for the remainder of an ignition cycle.

IVD Power/Charging should be More Robust

IVD battery discharge caused the IVD to turn off and become incapable of receiving and displaying safety events. Low battery charge was observed in all busses but was particularly acute in bus 3046. In response, both the IVD and power cord were replaced in bus 3046. The power cord replacement occurred on September 25, 2013. No observations of significant IVD discharge on bus 3046 were observed after the replacement. However, during the period extending from mid-August thru mid-September, observations of low battery charge level were reported on other busses.

The IVD power cable connection is insufficiently ruggedized for the operational environment – the cable was damaged and the IVD did not reliably charge, periodically causing the IVD to power down thus decreasing availability.

Additionally, there is evidence the IVD charger barely kept up when the screen was at full brightness. With the sun and other operational environment variability, it is conceivable that the IVD might have problems maintaining charge even when the cable is undamaged. A review of the power budget and possible redesign would be in order for a future system.

Additional IVD Logging Needed for More Effective Analysis

Additional IVD logging is needed for more effective analysis. The one second resolution at which data was logged should be increased for better analysis of the PCW and VTRW alerts and warnings. If possible, adding the BSM and Target Classification data used to create the VTRW alerts and warnings to the IVD logs would aid in debugging and analysis of the VTRW application. Depending on how often the data is logged, the data could be used to find false negative VTRW warnings and alerts.

The IVD log should be expanded to include information about the IVD charging system and battery state. This would assist in identifying IVD discharge and consumption rates, and may assist in resolving a systematic IVD charging issue that could influence future product design.

Summary of Revisions

The Proposed TRP and Applications Revisions Report lists candidate near term changes to the TRP system. Due to scope, budget, and time constraints, not all candidate revisions could be implemented under the current contract. Based on a combination of benefit, cost, and schedule criteria, the USDOT selected the following TRP revisions for redeployment. These TRP revisions were installed on the three UM Transit buses in January 2014, and successfully demonstrated to USDOT on January 24, 2014.

System-Wide, Non-Application-Specific Revisions

The following TRP Revisions impact all safety applications.

Verbal Notifications Instead of Beeps

The beeps provided during an alert condition were replaced with computer generated words specific to each alert. This change was driven by driver feedback and is intended to improve the IVD and increase driver acceptance. Table 3-14 lists the aural alert phrases employed for each safety application.

Table 3-14. TRP Safety Applications Aural Alerts

Application	Inform Alert Audio	Warning Alert Audio
Vehicle Turning Right	"Right Turn Vehicle Alert"	"Right Turn Vehicle Warning "
Pedestrian at Crosswalk Left	"Pedestrian Alert Left"	"Pedestrian Warning Left"
Pedestrian at Crosswalk Right	"Pedestrian Alert Right"	"Pedestrian Warning Right"
Forward Collision Warning	"Forward Collision Alert"	"Forward Collision Warning"
Emergency Electronic Brake Light Left	"Braking Ahead Left Alert"	"Braking Ahead Left Warning"
Emergency Electronic Brake Light Right	"Braking Ahead Right Alert"	"Braking Ahead Right Warning"
Emergency Electronic Brake Light Ahead	"Braking Ahead Alert"	"Braking Ahead Warning"
Curve Speed Warning Left	"Curve Speed Alert Left"	"Curve Speed Warning Left"
Curve Speed Warning Right	"Curve Speed Alert Right"	"Curve Speed Warning Right"

Source: Battelle

Display Cautions and Warnings Longer

The duration that alerts are displayed has been increased from 2 seconds to 3 seconds, if not superseded by a higher priority event. This change was driven by driver feedback and is intended to improve the IVD and increase driver acceptance.

Position IVD Closer to Operator

The IVD position was relocated to be closer to the driver. It was moved from the immediate right of the center bar of the front window, to the immediate left of the center bar of the front window, as shown in Figure 3-56, Final IVD Location[13]. This change was driven by driver feedback and is intended to improve the IVD and increase driver acceptance.

Source: Battelle

Figure 3-56. Final IVD Location

[13] The original design for Table location was the same as the final location (left of the center bar). Early in deployment the IVD location was moved right of the center bar to mitigate IVD WiFi interference with the bus radio. The WiFi frequency was subsequently changed, thus allowing the return to the original IVD location for the redeployment.

IVD Power Cable Robustness Mitigation

New IVD power cables were produced to the same design as the original cables (Battelle-produced custom cables utilizing the stock Samsung tablet computer connector). The cables on the buses were inspected for damage. None were found to require replacement, and the new cables served as onsite spares. These actions served to mitigate the possibility of IVD power loss due to a damaged cable, as occurred during the original deployment.

PCW Revisions

The following TRP Revisions impact the PCW safety application.

Decrease Crosswalk Detector Target Speed Threshold

The crosswalk detector target speed threshold was decreased from 7 MPH to 5 MPH. This change was intended to improve PCW accuracy, by decreasing false alerts caused by detection of a vehicle in the crosswalk. The rationale for this change was that a vehicle having a velocity component in the crosswalk direction (perpendicular to the road direction) greater than 5 MPH (rather than the previous setting of 7 MPH) would be excluded from detection. While joggers may no longer be detected, it was decided that the benefit of reducing the high rate of false alerts for vehicles outweighed the introduction of missed alerts for faster moving pedestrians. The theoretical effects of this change are shown in combination with the Verification Time setting change in the next section (Figure 3-58).

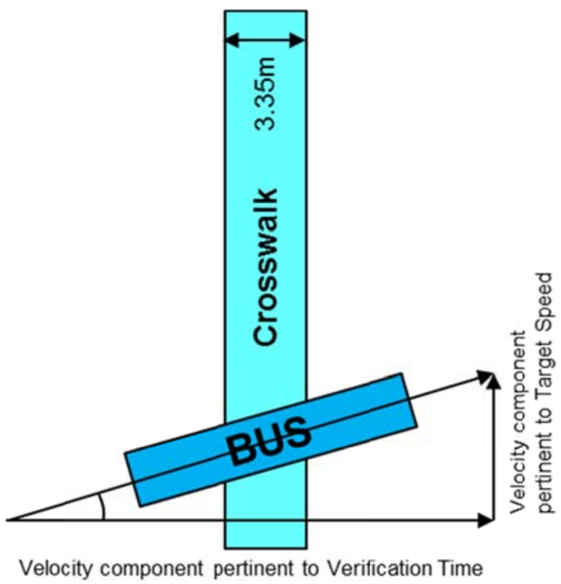
Increase Crosswalk Detector Verification Time Setting

The crosswalk detector verification time setting was increased to approximately 3.5 seconds. As with the target speed threshold, the verification time change was intended to improve PCW accuracy, by decreasing false alerts caused by detection of a vehicle in the crosswalk. The rationale for this change was that a vehicle passing through the crosswalk in less than 3.5 seconds (rather than the previous setting of approximately 2.5 seconds) would be excluded from detection. While detection of pedestrians stepping into the crosswalk may be slightly delayed, it was decided that the benefit of reducing the high rate of false alerts for vehicles outweighed the introduction of slightly late alerts in some situations.

Implementation of this change included the following steps:

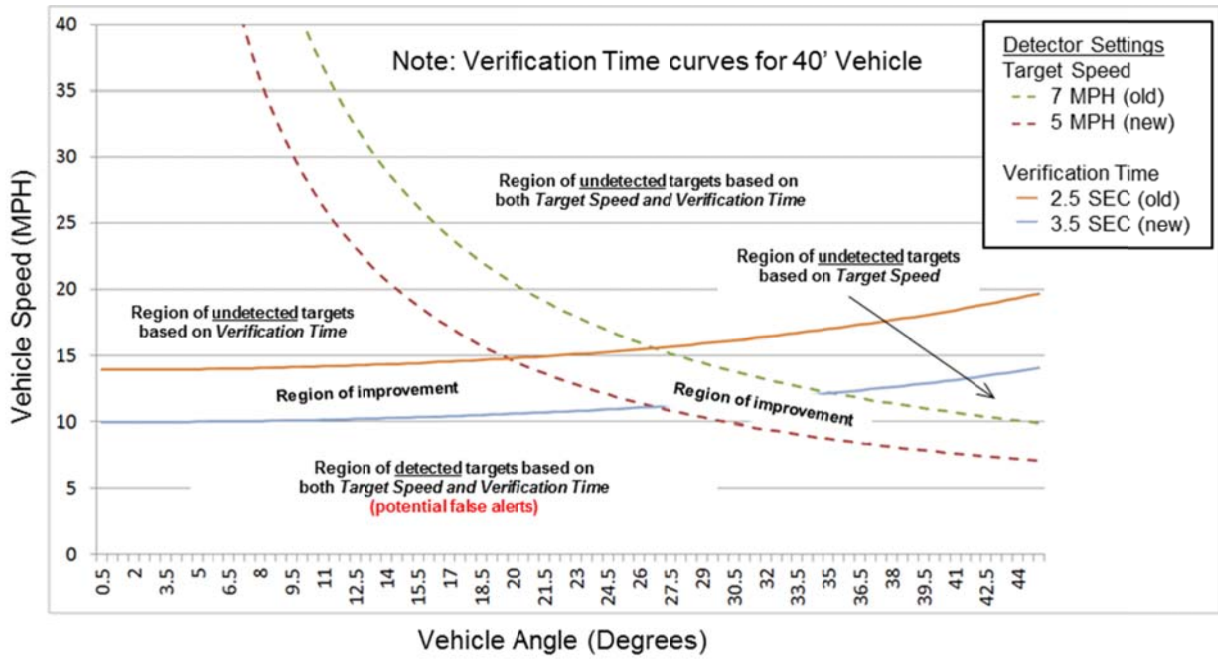
- Before making the change, the intersection was monitored for false detections, specifically waiting for buses and slow moving vehicles to move through the intersection. Only the detector facing North across Fuller was observed to exhibit regular occurrence of false detections. It was decided to only adjust this unit's verification time.
- The verification time was adjusted by turning the pot slightly right to the 1:00 position (viewed as a clock). The original position was noon, 1/2 turn on the pot.
- After making the change, the intersection was monitored for approximately 30 minutes. A few false detections were observed (2 or 3), which seemed to be an improvement.
- Testing with a pedestrian showed a less prompt detection of the pedestrian when stepping off the inner (West) edge of the crosswalk (North across Fuller), with the detection occurring a few feet off the curb. The East edge of crosswalk worked well (prompt detection). Note the West edge is closer to the detector, thus causing the difference in detection position.

Figure 3-57 shows how the velocity components of a vehicle traversing the crosswalk at an angle determine whether a vehicle will be detected. Only the velocity component perpendicular to the crosswalk is pertinent to the Verification Time, while only the velocity component parallel to the crosswalk is pertinent to the Target Speed. Figure 3-58 shows the theoretical effects of the revised settings as compared to the previous settings. Vehicle length affects the Verification Time since it takes a longer vehicle more time to traverse the crosswalk. The more problematic case (from the perspective of false detections) of a bus is shown. As shown in the figure, the net impact of the changes theoretically results in false detections for buses occurring at approximately 12 MPH (at 26°) or less for the new settings, as compared to 16 MPH for the previous settings. For cars (not shown), theoretically false detections occur at 7 MPH (at 45°) or less for the new settings, as compared to 9 MPH for the previous settings.



Source: Battelle

Figure 3-57. Vehicle Velocity Components Pertinent to Detection

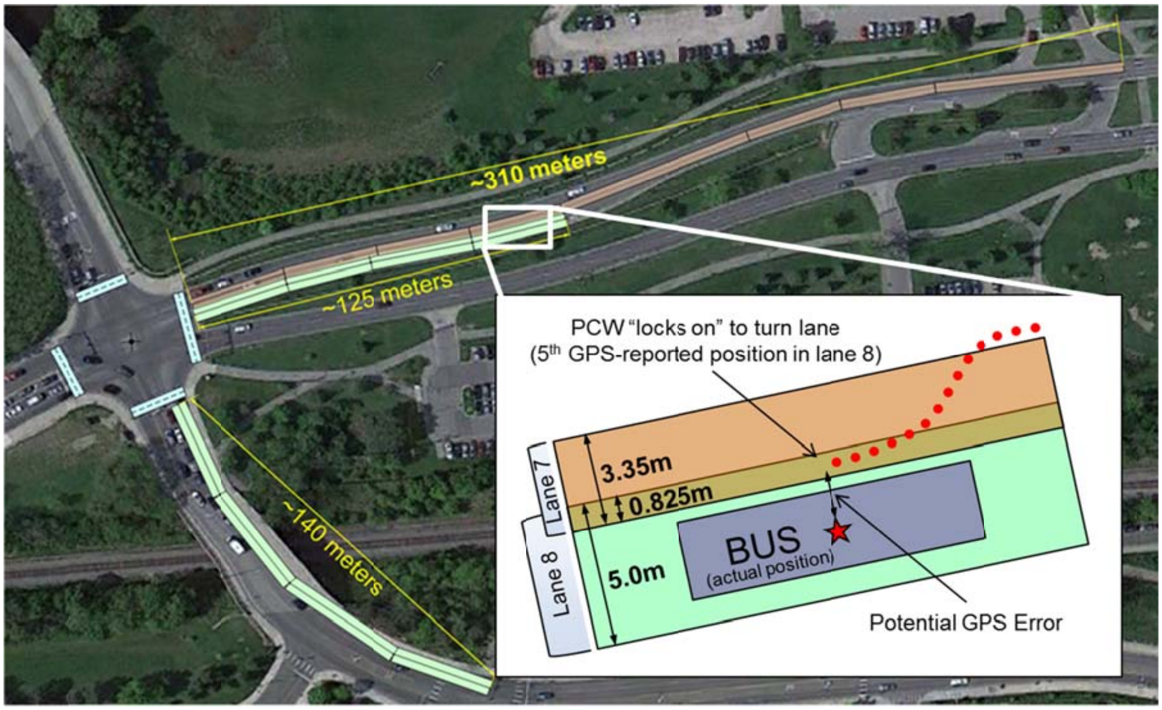


Source: Battelle

Figure 3-58. Revised Target Speed & Verification Time Effects

Modify PCW Setting to Not Display Alerts when Bus is in Lane 7

The PCW setting was modified to exclude Lane 7 (straight lane) as a turn lane. This change on its own would reduce PCW false alerts when the bus and GPS-reported position are in Lane 7, though it could also result in missed alerts when the bus is in Lane 8 (turn lane) with a GPS error placing the bus in Lane 7. To mitigate the risk of missed alerts, the PCW lane tracking algorithm was also modified to favor the turn lanes by “locking on” after meeting the criteria that the bus is in the turn lane. The criteria for “in the turn lane” was also loosened by widening the turn lane (as viewed by the PCW algorithm) to 5 meters, and to require only 5 consecutive GPS-reported positions in the lane to lock on. Figure 3-59 depicts the revised criteria for turn lane determination.



Source: Battelle, Google Inc.

Figure 3-59. Revised Turn Lane Criteria

The net impact of these changes was intended to improve PCW accuracy by reducing false alerts for buses traveling straight, while mitigating the risk of introducing missed alerts for buses truly turning when there is GPS error placing the bus in the straight lane.

Change when PCW Alerts are Dismissed

The PCW application was modified to transition to an inactive state and dismiss PCW alerts when the bus is in the crosswalk (not past it). The modification uses the buses center position and once it enters the crosswalk polygon, dismisses active alerts and suppress any further alerts. The rationale for this change is that once the front of the bus is past the crosswalk any new alerts would not be of concern to the driver. The impact of this change was intended to improve PCW accuracy by reducing nuisance alerts.

VTRW Revisions

The following TRP Revision impacts the VTRW safety application.

Don't Display VTRW Alerts when Gear is Not in Forward Drive

Based on the analysis of deployment data and feedback from the bus drivers, the VTRW application was modified to transition to an inactive state and not display VTRW alerts when Gear Position is not in forward drive (not "D" or "L"). Gear status from the CAN bus was determined to be available based on testing performed in January 2014, thus allowing Gear Position to be used as another criteria (in addition to brake pedal) for determining the driver's "intent to proceed". The impact of this change was intended to improve VTRW accuracy by reducing nuisance alerts.

Redeployment Analysis

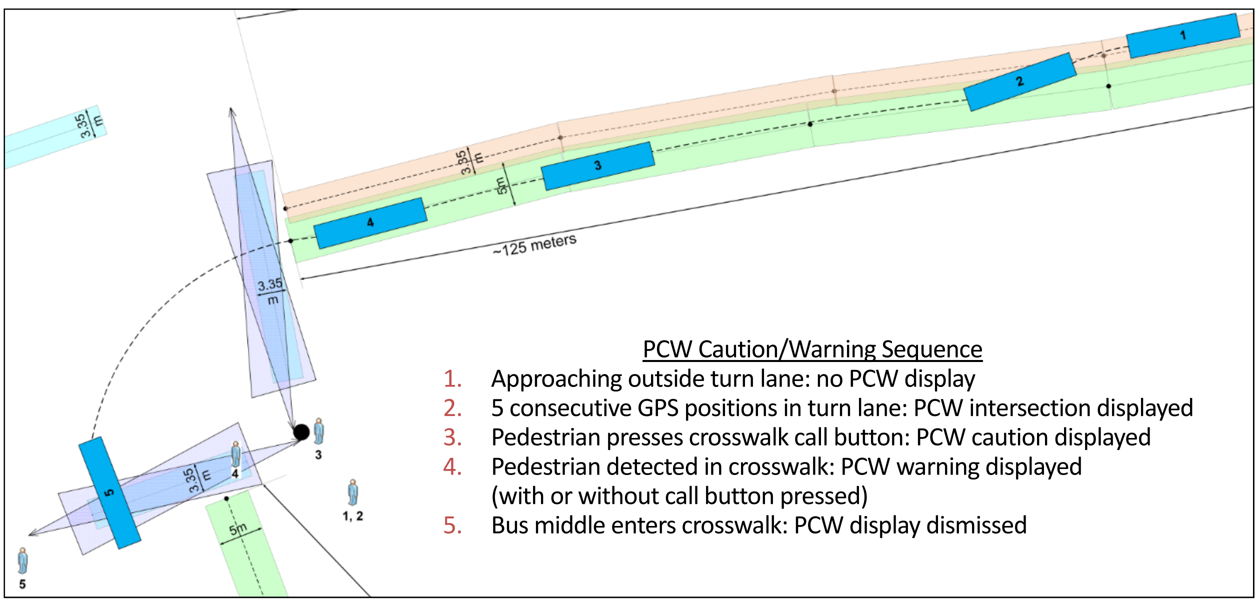
Battelle collected data from the redeployed system for a one-month period, from February 10, 2014, through March 10, 2014.

Battelle used IVD data and DAS bus video to perform an assessment of TRP system accuracy. The set of alerts analyzed was based on IVD data for which DAS data also existed. PCW Warnings as well as VTRW Cautions and Warnings were analyzed, analogous to the original deployment analysis. Considering time and budget constraints, PCW Cautions were not included since they weren't included in the original analysis, and since they would provide limited value added (PCW Caution analysis would provide additional cases of lane tracking for analysis; crosswalk call button functionality is highly reliable).

Pedestrian in Crosswalk

Eighty-four (84) PCW Warnings were analyzed for the February/March redeployment period. Battelle used DAS bus video to determine both bus path and pedestrian presence in the crosswalk. Battelle used GPS data recorded by the IVD, for failure analysis related to lane tracking.

Figure 3-60 provides a summary of the PCW alert criteria and sequence of events, for the PCW algorithm as designed.



Source: Battelle

Figure 3-60. PCW Alert Sequence

Valid warnings were determined by the presence of a pedestrian in one of the two application-supported crosswalks and the bus being on the path that traverses through the crosswalk.

Invalid warnings were determined by conclusive video evidence that a pedestrian was not present in the crosswalk or the bus wasn't on the path that traversed through the crosswalk (or both).

Warnings categorized as Unsure were due to the video being too grainy, too dark, or too far away to allow presence of a pedestrian in the crosswalk to be conclusively determined. Bus path was determined in all cases, thus no alerts of unsure validity were the result of unsure bus path.

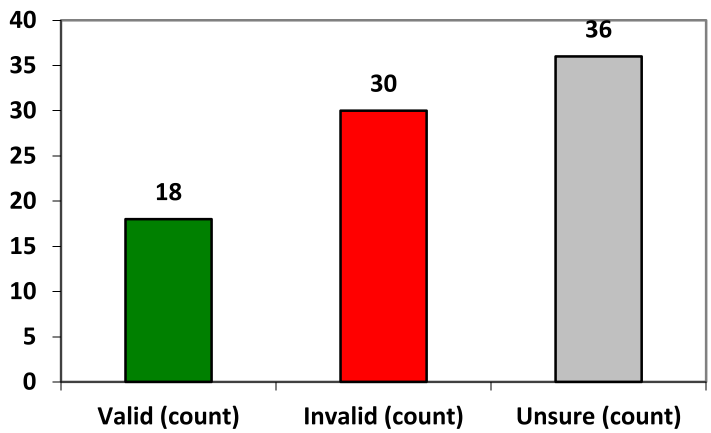
Table 3-15 provides a PCW validity decision matrix, based on the criteria described above.

Table 3-15. PCW Warning Validity Matrix

Bus Path	Validity If Pedestrian In Crosswalk	Validity If Pedestrian Not In Crosswalk	Validity If Unsure Pedestrian In Crosswalk
Bus Path Through Crosswalk	Valid	Invalid	Unsure
Bus Path Not Through Crosswalk	Invalid	Invalid	Invalid
Unsure If Bus Path Through Crosswalk	Unsure	Invalid	Unsure

Source: Battelle

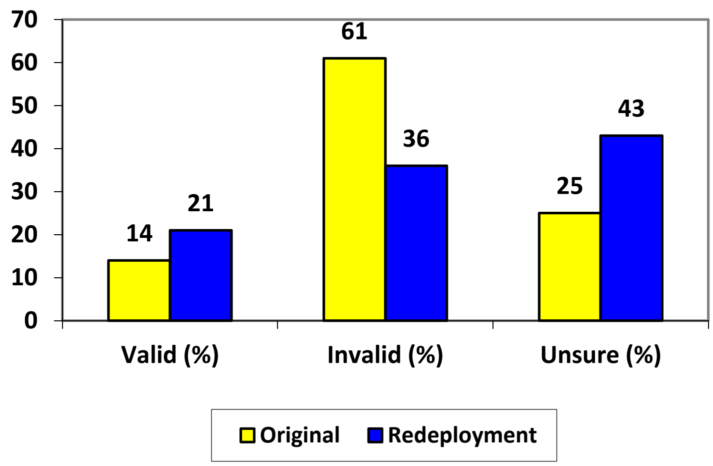
Figure 3-61, PCW Redeployment Warning Analysis Results, shows the breakdown of Valid, Invalid, and Unsure PCW Warning counts based on Battelle analysis.



Source: Battelle

Figure 3-61. PCW Redeployment Warning Analysis Results

Figure 3-62, PCW Original vs. Redeployment Warning Analysis Results, shows the breakdown of Valid, Invalid, and Unsure PCW Warnings (as a percentage of total Warnings) for the Original versus Redeployment period using the same assessment criteria. For the redeployment period, a 50% increase in Valid Warnings, and a 41% decrease in Invalid Warnings was observed.

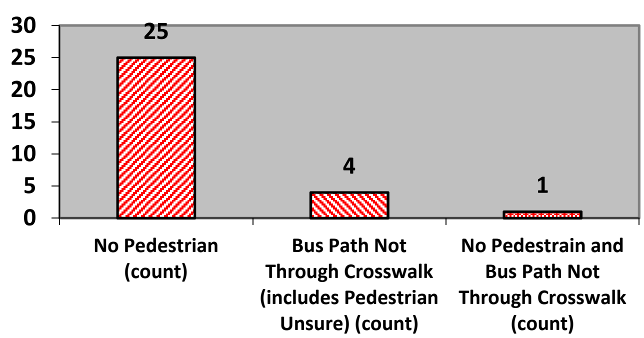


Source: Battelle

Figure 3-62. PCW Original vs. Redeployment Warning Analysis Results

A breakdown of the Invalid alerts is provided in Figure 3-63, PCW Redeployment Invalid Analysis Results. As shown in the figure, the majority of invalid alerts were caused by no pedestrian in the crosswalk. Based on video review, the cause for these "false positive" alerts was that that the pedestrian motion detectors detected a vehicle in the crosswalk – either the tail end of the host bus, or another slow moving vehicle – the same reason as during the original deployment.

Unlike the original deployment, the redeployment had one case where the pedestrian was located on the sidewalk at the time of alert, presumably the reason for the detection. It is possible the replacement[14] and/or adjustment[15] of the subject detector resulted in this false crosswalk detection, since it was not seen in the original deployment for a larger data harvest. In any case, this false Warning is categorized as "No Pedestrian".



Source: Battelle

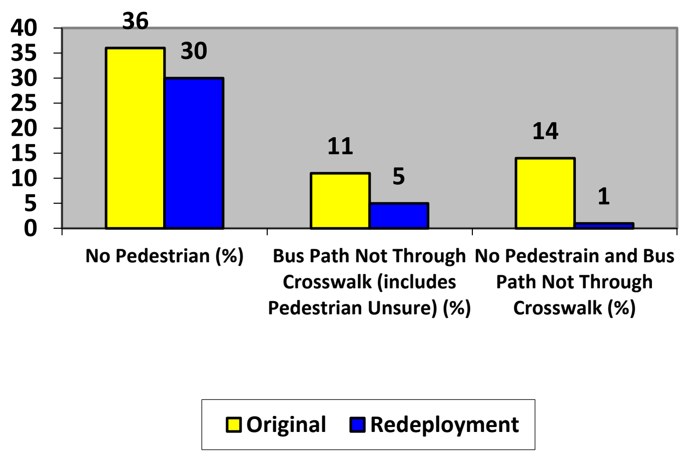
Figure 3-63. PCW Redeployment Invalid Analysis Results

[14] Three of four crosswalk detectors became non-operational after an electrical storm in fall of 2013 and were replaced and configured/adjusted in January 2014, prior to redeployment.
[15] All four crosswalk detectors were adjusted as part of system refinements.

The other cause – "Bus Path Not Through Crosswalk" – occurred because the PCW algorithm projected the bus path to be through the crosswalk when in fact the bus was not in the turn lane and traveled straight through the intersection.

One warning had no pedestrian in the crosswalk and the bus traveled straight through the intersection, in which case it was invalid for both reasons with the event being triggered by another vehicle in the crosswalk.

Figure 3-64, PCW Original vs. Redeployment Invalid Analysis Results, shows the breakdown of Invalid Warnings (as a percentage of total Warnings) for the Original versus Redeployment period. For the redeployment period, a 38% decrease (50% to 31%) in Invalid Warnings caused by a lack of pedestrian was observed, while a 76% decrease (25% to 6%) in Invalid Warnings caused by the bus path was observed.



Source: Battelle

Figure 3-64. PCW Original vs. Redeployment Invalid Analysis Results

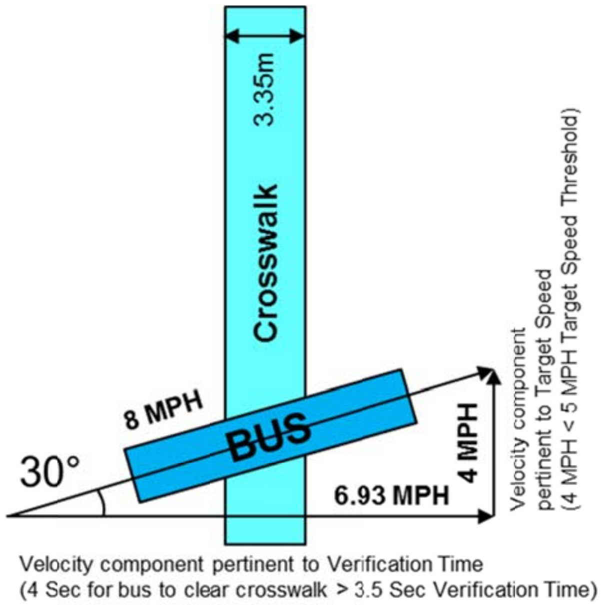
For the redeployment, Battelle has concluded there are two main root causes which resulted in invalid PCW alerts:

- Crosswalk detectors cannot accurately distinguish pedestrians from vehicles
- GPS Inaccuracy

Crosswalk Detectors Cannot Accurately Distinguish Pedestrians from Vehicles

While crosswalk detector adjustments for the redeployment improved PCW performance, the detectors' inability to accurately distinguish pedestrians from vehicles continued to be the largest root cause of invalid PCW warnings.

Prior to the original deployment, the detectors were modified to ignore objects moving faster than 7 MPH (velocity component in direction of the crosswalk) and to ignore objects if detected for less than a verification period of approximately 2.5 seconds. For the redeployment, these thresholds were changed to 5 MPH and approximately 3.5 seconds, respectively. While these adjustments reduced false detections, vehicles moving through the crosswalk slowly at an angle continued to trigger false detections. Figure 3-65 shows an example of how a vehicle could be detected with the revised detector settings.



Source: Battelle

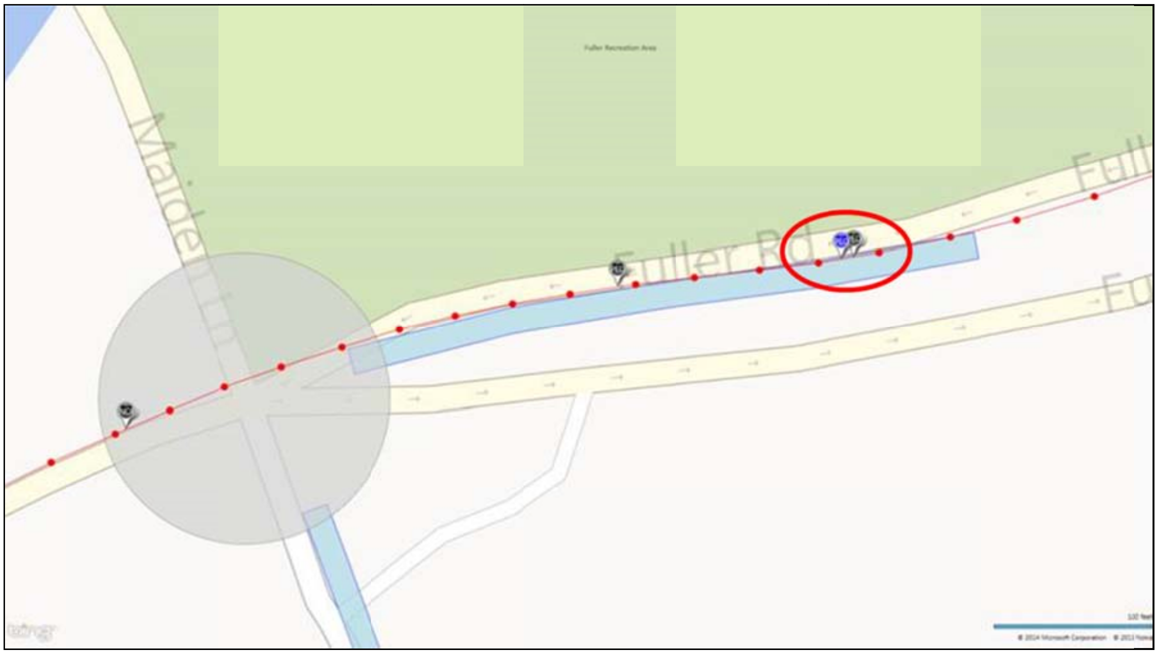
Figure 3-65. No Pedestrian Example (Vehicle Detection)

GPS Inaccuracy

Scenario 1: As a direct result of GPS error, a bus can actually be located in a straight lane with its GPS-reported position in the turn lane. Based on the inaccurate GPS position, the TRP system determines the bus is in the turn lane when in fact it is not, thus enabling alerts and resulting in false warnings when a pedestrian is detected in the crosswalk.

Scenario 2: For the redeployment, with the removal of Lane 7 (straight lane) as PCW-enabled, the lane determination algorithm was modified to "favor" the turn lanes to diminish the possibility of introducing missed alerts (see Section 4.2.3). As a result, a bus can actually be located in a straight lane with its GPS-reported position in the outer region of the straight lane, and the TRP system will determine the bus is in the turn lane. In this scenario, even though the GPS-reported position is within the bounds of the lane the bus is actually in, such false alerts are attributed to GPS Inaccuracy since the PCW algorithm as designed is necessary to accommodate GPS error, favoring false alerts over missed alerts.

Figure 3-66 shows an actual case where the reported GPS position of the bus dipped into the left turn lane long enough to lock on to the lane, when the bus was actually in the straight lane. The blue region is the PCW-defined turn lane. The bus path is shown in red. Each point is a GPS-reported bus position at one-second intervals. The GPS position is actually received at one tenth second intervals; therefore, half the distance between points in the figure dipping into the blue region would result in the PCW application locking on to the turn lane, thus enabling PCW alerts. The circled region shows where lane-lock occurred, followed by the invalid alert.



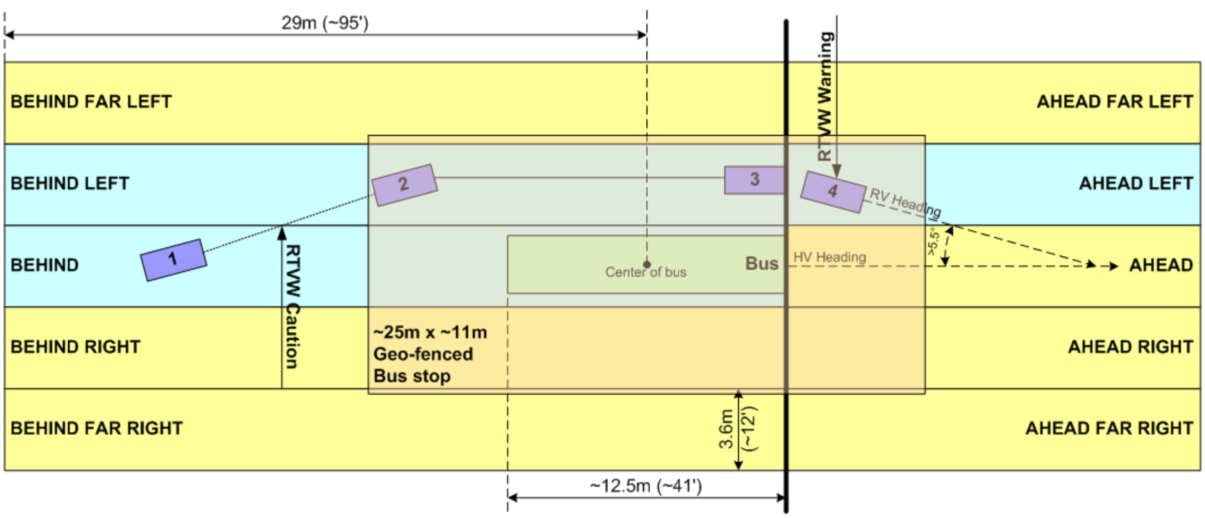
Source: Battelle, Microsoft Corp.

Figure 3-66. Bus Path Not Through Crosswalk (GPS Inaccuracy)

Vehicle Turning Right in Front of Bus

Ten (10) VTRW Alerts (7 cautions and 3 warnings) were analyzed for the February/March redeployment period. Two (2) of these alerts (1 caution, 1 warning) were determined to be continuations of other included alerts, though they were counted as separate alerts for consistency with the original analysis and delivered data files.

Figure 3-67 provides a summary of the VTRW alert criteria and sequence of events, for the VTRW algorithm as designed.



Source: Battelle

Figure 3-67. VTRW Target Classification and Alert Sequence

Valid alerts were determined by the RV following the prescribed path relative to the HV at an application-supported bus stop and the driver having “intent to proceed”. “Intent to proceed” is determined by the HV Brake Pedal not being depressed and the HV Gear Position being in forward drive (“D” or “L”) after the HV has stopped within the geo-fenced bus stop. The RV prescribed path to generate a cautionary alert is from Behind, to Behind Left, as shown in Figure 3-67. The prescribed path to generate a warning is from Behind, to Behind Left, to Ahead Left, followed by a 5.5% turn into the direction of the HV.

The relative position of the RV to the HV (Behind, Behind Left, Ahead Left, etc.) is termed the Target Classification, and is calculated based on the contents of the RV and HV BSMs. The Target Classification “grid” moves and rotates as with the bus, and the VTRW algorithm is only concerned with the relative positions of RV and HV, not the position of the vehicles relative to the stationary bus stop and surrounding lanes. This can result in alerts even though in some cases there may actually be little notion of an RV passing maneuver.

Invalid alerts were determined by evidence that the RV did not follow the prescribed path relative to the HV or the HV Brake Pedal was depressed or the HV Gear Position was not in forward drive (or any combination).

Alerts categorized as Unsure were due to lack of evidence to make a conclusive determination of the RV path relative to the HV. Brake Pedal status was determined in all cases (never Unsure), and furthermore was always Not Depressed (no Invalids due to Brake Pedal depressed). Gear Position was determined in all cases (never Unsure), and furthermore was always “D” or “L” (no Invalids due to Gear Position not “D” or “L”).

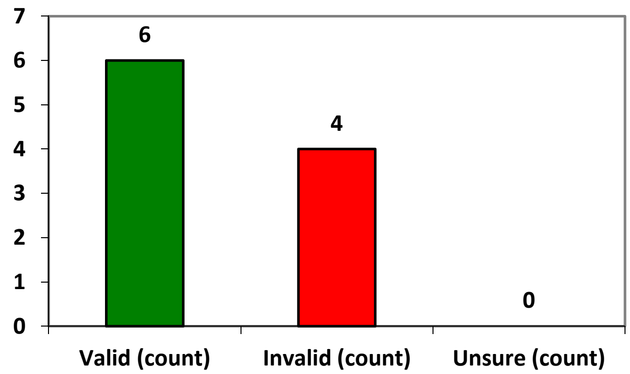
Table 3-16 provides a VTRW validity decision matrix, based on the criteria described above.

Table 3-16. VTRW Alert Validity Matrix

Brake Pedal and Gear Position	Validity If RV Follows Prescribed Path	Validity If RV Doesn’t Follow Prescribed Path	Validity If Unsure RV Follows Prescribed Path
Brake Pedal Not Depressed and Gear Position is “D” or “L”	Valid	Invalid	Unsure
Brake Pedal Depressed or Gear Position is not “D” or “L”	Invalid	Invalid	Invalid
Unsure If Brake Pedal Not Depressed and Gear Position is “D” or “L”	Unsure	Invalid	Unsure

Source: Battelle

Figure 3-68, VTRW Redeployment Alert Analysis Results, shows the breakdown of Valid, Invalid, and Unsure VTRW Alerts based on Battelle analysis (cautions and warning are grouped together, as with the original analysis report).



Source: Battelle

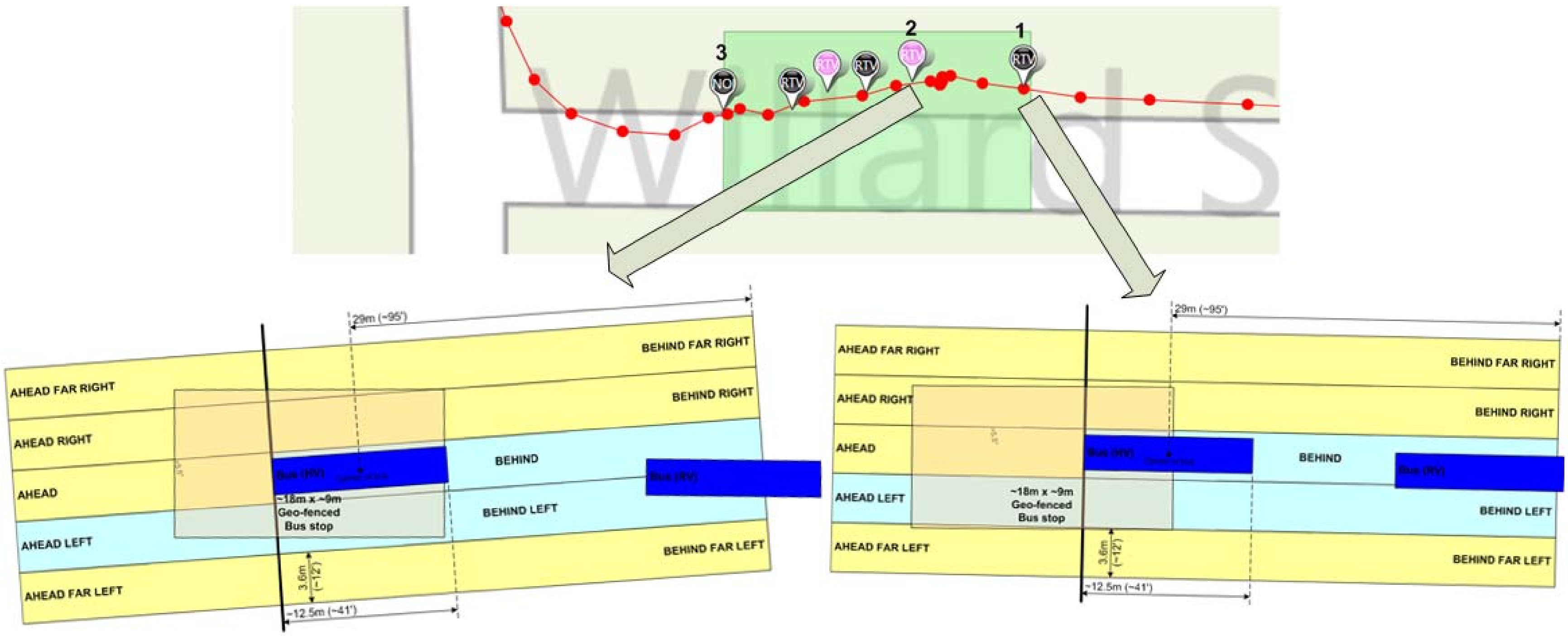
Figure 3-68. VTRW Redeployment Alert Analysis Results

Included in the 6 valid alerts were 2 cautions (continuation of same “event’) that were assessed as valid based on design (relative position of the RV to the HV) that would have been assessed as invalid if based on strict CONOPS scenarios (RV passing maneuver). Figure 3-69 shows this case. If the continuation events were combined (2 cases) the results would be 4 valid and 4 invalid. If the one combined event that was valid due to relative position design was deemed invalid, the results would be 3 valid and 5 invalid.

The top portion of Figure 3-69 shows the sequence of events recorded within the IVD log mapped to the geographic location of the bus at the time they were recorded.

- Black RTV symbols indicate the bus was within the geo-fenced bus stop with no alerts
- Purple RTV symbols indicate a RTVW warning was issued to the driver
- Black NO (none) symbol indicates the bus was exiting the geo-fenced bus stop

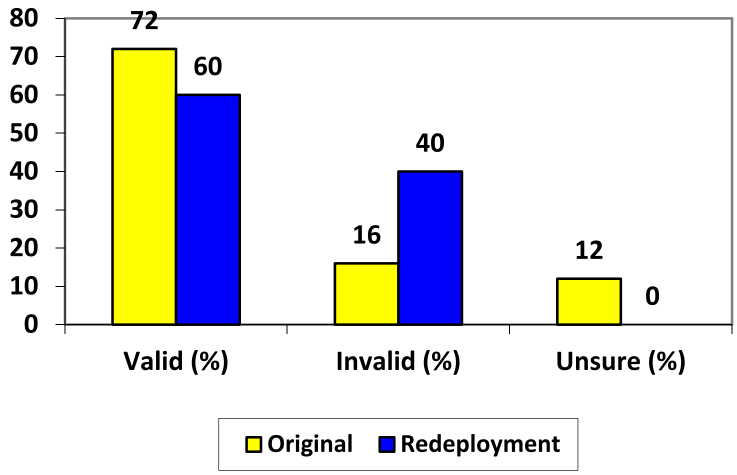
In the bottom-right portion of Figure 3-69, the RV is shown with a Target Classification of “Behind”, after the bus entered the geo-fenced zone. In the bottom-left portion of the figure, the bus emerged from the bus stop and turned toward the center of the road, thus the bus reference frame shifted (rotated) and the RV classification changed from “Behind” to “Behind Left” even though it remained physically stationary. The RV relative position changed triggering the alert consistent with the design.



Source: Battelle, Microsoft Corp.

Figure 3-69. VTRW Alert based on Relative Position

Figure 3-70, VTRW Original vs. Redeployment Alert Analysis Results, shows the breakdown of Valid, Invalid, and Unsure VTRW Alerts (as a percentage of total Warnings) for the Original versus Redeployment period using the same assessment criteria. Given the small redeployment dataset, conclusions cannot be drawn with confidence.



Source: Battelle

Figure 3-70. VTRW Original vs. Redeployment Alert Analysis Results

While the Gear Position change was expected to lower the number of VTRW alerts, no data exists to measure this effect. It was not expected to affect the validity rate of remaining alerts (given that prior to the change, alerts weren't considered invalid based on Gear Position since it was assumed buses would be in forward gear while at bus stops).

All Invalid alerts were due to the RV not following the prescribed path relative to the HV.

Unchanged from the original deployment, for the redeployment Battelle has concluded there is one main root cause which resulted in invalid VTRW alerts:

- Incorrect Target Classification caused by GPS Error

Incorrect Target Classification caused by GPS Error

The same as for the original deployment, Incorrect Target Classification is the direct cause for invalid VTRW alerts, with the root cause believed to be GPS accuracy as stated by DENSO.

GPS error also causes potentially inaccurate bus headings, used by the Target Classification algorithm to set the "grid" orientation. Heading is determined by GPS data, and DENSO testing has shown that calculated headings can fluctuate significantly at slow speeds. The TRP Target Classification algorithm is configured to latch on to the calculated heading when the bus reaches a speed below 2.016 kilometers per hour (KPH) (just a little more than 1 MPH), while unlatch occurs when the bus exceeds 2.988 KPH.

The mini-WSU is equipped with a WAAS-enabled GPS receiver. The GPS receiver is a "black-box" chip on the mini-WSU mainboard. DENSO currently has logic in place to stabilize and "coast" the GPS data in known troublesome conditions, like low speed and weak GPS signal strength.

Revisions Impacts Summary

The following tables summarize the impact of each TRP revision, based on the data analysis and driver feedback presented in earlier sections of this report. As can be seen in these tables, results suggest that each change (group of two changes in the case of the crosswalk detectors) had the desired positive impact on the TRP system.

Table 3-17. Non-Application-Specific Revisions Impacts

Revision	Impact
Verbal notifications instead of beeps	Improved IVD: Driver doesn't need to look away from road to know type of alert. Focus group participants agreed this revision was an improvement.
Display cautions and warnings longer	Improved IVD: Driver has longer to recognize alerts. Focus group participants found the increased time to be helpful.
Position IVD closer to operator	Improved IVD: The IVD closer to the driver is less distraction from looking at the road. Focus group participants agreed the new position for the IVD was good.
IVD power cable robustness mitigation – produce new cables and replace on bus if damaged	Improved Availability: Risk of damaged cables causing loss of IVD power was mitigated. Reported occurrences of unpowered IVDs during redeployment were not the result of damaged power cables. The cables were undamaged and did not need to be replaced for the IVDs to return to normal operation.

Source: Battelle

Table 3-18. PCW Revisions Impacts

Revision	Impact
Decrease crosswalk detector target speed threshold from 7 MPH to 5 MPH Increase crosswalk detector verification time setting to approximately 3.5 seconds	Improved Accuracy: 38% decrease (50% to 31%) in Invalid Warnings caused by a lack of pedestrian
Modify PCW setting to not display Alerts when bus is in Lane 7 (straight lane)	Improved Accuracy: 76% decrease (25% to 6%) in Invalid Warnings caused by the bus path
Change when PCW Alerts are dismissed – when bus in crosswalk (not past it)	Improved Accuracy: Removal of all PCW nuisance alerts after bus passes middle of crosswalk. Observed in bus video and corroborated by focus group participants.

Source: Battelle

Table 3-19. VTRW Revisions Impacts

Revision	Impact
Don't display VTRW alerts when gear position is not in forward drive	Improved Accuracy: Removal of all VTRW nuisance alerts when there is no "intent to proceed" as determined by bus not in forward gear. While redeployment bus data does not exist to assess this change, the change was verified as part of on-bus integration activities in January 2014, and demonstrated to US DOT prior to redeployment on January 24, 2014.

Source: Battelle

Recommended Next Steps

This section provides a summary of recommended next steps, based primarily on the analysis and lessons learned of the previous section. Chapter 4, Vision of Next Generation TRP, conceptually moves forward many of these recommendations with a vision for a next generation system.

Improved Pedestrian Detection Sensing Technology

A solution that uses newly-emerging technologies is recommended. Pedestrian detection is a key technology in computer vision with uses extending beyond automotive safety into robotics and surveillance. With multiple important applications that have significant commercialization opportunities, advances in pedestrian detection sensors are continual and accelerating. As technology has advanced, it has become increasingly practical to deploy a high-speed imaging system capable of effectively operating across a broad range of environmental conditions. Future TRP-like projects requiring pedestrian detection will need to survey the portfolio of existing and emerging products for source selection. In addition to improved accuracy, a natural result of employing a more discerning technology will be detection and alerting for joggers and bicyclists.

Improved Locational Accuracy Technology

Using an IMU to aid the GPS unit in location accuracy should increase accuracy to a level that could be used reliable for lane detection. The algorithm would use a good initial GPS fix and calculate sequential positions based on the data from the IMU. That calculated position would be compared to the GPS position, and a filter or averaging algorithm would then be used to generate a position to be used by both the VTRW and PCW applications.

Another option would be to implement Differential GPS with a localized fixed point providing accuracy corrections to a specific localized implementation of TRP.

Ultimately, a comprehensive assessment of emerging technologies that would provide the locational accuracy required by TRP is recommended.

Human Factors Assessment-based Revisions

A ground-up Human Factors assessment of what makes sense for the TRP within the bus driver workspace should be performed. The analysis would include an evaluation of the available real estate, an evaluation of the way that the alerts are presented to the driver that includes identification, ranking and selection of the best visual presentation approach. One of the evaluation criterion for the visual presentation alternatives would be the amount of screen real estate (pixels, physical dimension). For example, the result could suggest that the visual medium change from an IVD to an in-dash Liquid-crystal Display (LCD).

WSU Reset Elimination

The root cause of the WSU reset within the WSU firmware should be determined and resolved. Within the TRP, WSU resets lead to small intermittent windows of approximately 20 second duration where all safety and transit applications are disabled while the WSU recovers.

IVD/Cable Ruggedization

A ruggedized IVD/cable/connector should be employed for a production system in this operational environment.

IVD Power Budget/Management Review

A review of the power budget and possible redesign should be performed for a future system.

Software Design Changes to Reduce Nuisance Alerts

The Transit-Specific Safety Application designs can be further refined to exclude nuisance alert situations where there is no safety hazard or imminent danger. As one example, the distance the PCW application displays alerts when approaching the intersection should be reduced, and warnings should only be issued for imminent collisions (as the bus approaches the crosswalk, which is occupied by a pedestrian). As another example, the VTRW algorithm should be refined to more accurately determine if the RV is following the prescribed hazardous path that would generate an alert – such as by considering RV velocity relative to HV, in addition to Target Classification.

Extend Application of Transit Safety Applications

The PCW application could be extended to be used anywhere RSE could be installed, such as for mid-block pedestrian crossings. The PCW application could also use direct Vehicle-to-Pedestrian (V2P) communications, thus not having to rely on infrastructure to detect pedestrians. The VTRW application should be extended to work at any bus stop, and could be extended for more generic use outside of bus stops (serving as a general purpose blind spot / lane change application).

Additional Logging / Monitoring Capability

Future research and development systems should include the ability to identify false negatives as a part of the analysis and evaluation, which was a limitation of this project. A subset of false negatives were due to equipment unavailability (malfunctioning equipment). A lesson learned from the overall Model Deployment was that the RSUs/ RSE should include the capability for operating agencies to remotely monitor the equipment health (and provide diagnostics) in real-time. One of the problems in the Model Deployment was that the RSE may not have been functioning properly and it was not known in real time. The same could be said about the capability to monitor the TRP OBE in real-time, which was partially addressed by the DAS in the Model Deployment.

Table 3-20 lists the recommended next steps categorized by application, along with the type of benefit that would result from performance.

Table 3-20. Recommended Next Steps

Recommended Next Step	Area of Impact	Benefit
Improved Locational Accuracy Technology	System	Improved Accuracy
Human Factors Assessment-based Revisions	System	Improved IVD
WSU Reset Elimination	System	Improved Availability
IVD/Cable Ruggedization	System	Improved Availability
IVD Power Budget/Management Review	System	Improved Availability
Additional Logging / Monitoring Capability	System	Improved Accuracy and Availability
Improved Pedestrian Detection Sensing Technology	PCW	Improved Accuracy
Software Design Changes to Reduce Nuisance Alerts	PCW	Improved Accuracy
Extend Application of Transit Safety Applications	PCW	Improved Safety
Software Design Changes to Reduce Nuisance Alerts	VTRW	Improved Accuracy
Extend Application of Transit Safety Applications	VTRW	Improved Safety

Source: Battelle

Chapter 4 Vision of Next Generation TRP

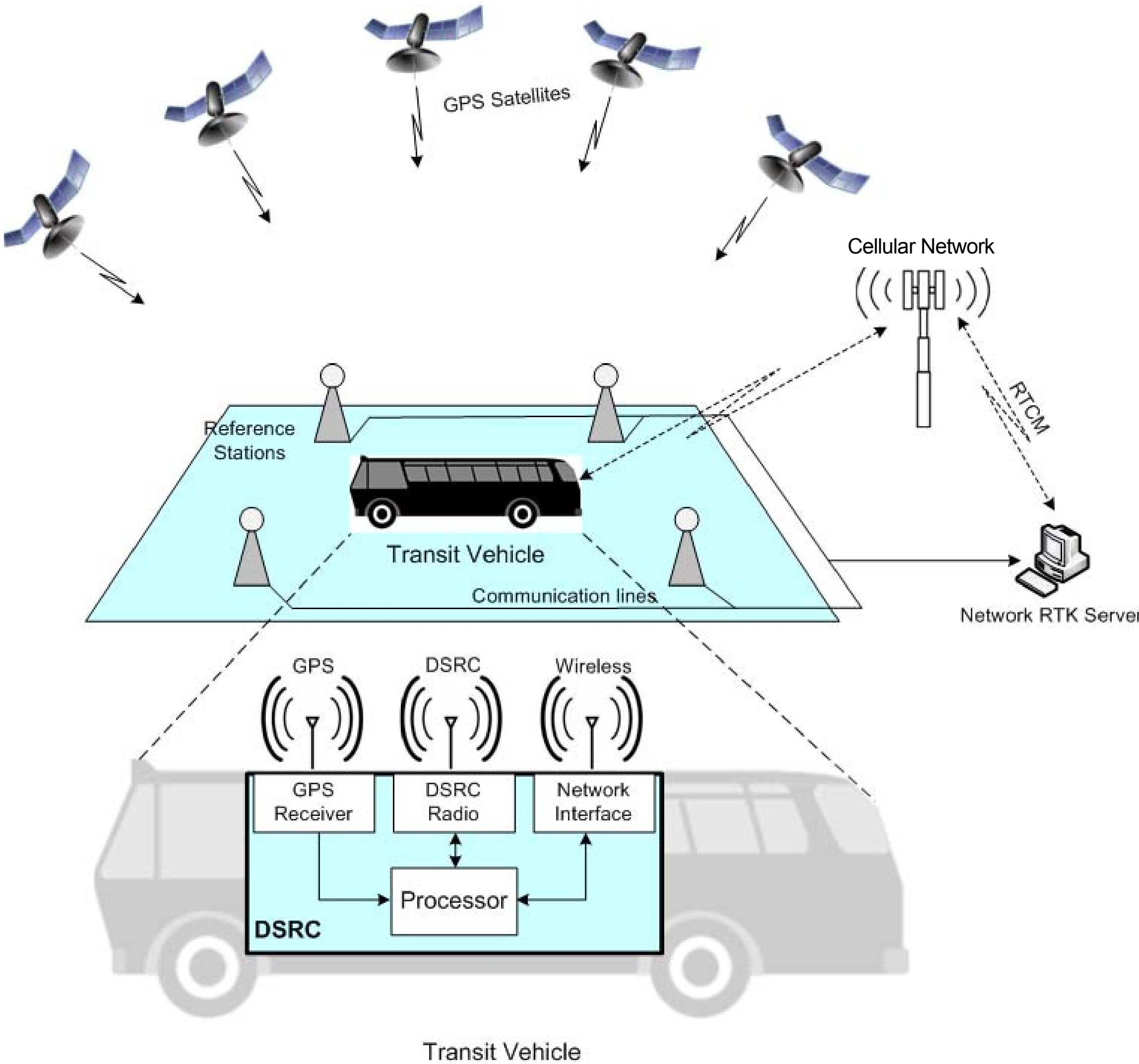
The vision for the next generation TRP includes strengthening known weaknesses, and employing new technology that provides better integration with existing transit system technology and enhanced safety application performance.

Next Generation Vehicle Positioning

This section describes next generation TRP enhancements to improve the accuracy of the vehicle location prediction. Locational accuracy is a critical need for TRP safety applications. Poor accuracy has been identified as a source of degraded TRP performance. The next generation TRP will rely on an improved GPS accuracy and a fusing of location information from different sensor types.

CORS-Based Differential GPS Correction

Recently Battelle has developed and demonstrated a practical technique to improve locational accuracy on existing commercial DSRC equipment. The system applies Differential GPS (DGPS) corrections received in Radio Technical Commission for Maritime Services (RTCM) 2.3 messages from a regional Continuously Operating Reference Station (CORS) network. A CORS network is a network of Real-Time Kinematic (RTK) base stations. Figure 4-1 below portrays the data flow from the CORS network to the TRP-equipped transit vehicle. Applying DGPS corrections will provide an improvement in transit vehicle locational accuracy.



Source: Battelle

Figure 4-1. CORS-Based Differential GPS Data Flow

Localized IMU Data

GPS errors are generally bounded. IMU errors tend to grow in time without bound. The complementary nature of the error accumulation facilitates an integrated system in which it is possible to reach higher levels of accuracy. In areas where the GPS reception is challenged due to multi-path or minimal satellite visibility (constellation strength), the IMU can provide a localized reference for increasing locational accuracy.

An IMU was fielded as an adjunct element of the TRP. It was mounted on the underside of the bus along a carriage-supporting cross member located just behind the front axle. There was an initial intent to employ the IMU data. IMU data was received and analyzed by DENSO on both TRP and RSD vehicles. The longitudinal acceleration data from the IMU was slightly less noisy than the GPS-derived longitudinal acceleration data. The yaw rate data from the IMU was significantly more noisy than the GPS-derived data. Although the IMU was assessed as ineffective in improving accuracy, in general, the use of an IMU for location accuracy improvement is believed to be a technically sound approach. Determining and mitigating the primary causes of the unacceptable IMU performance should facilitate a beneficial reintroduction of the IMU into the next generation TRP.

For the TRP transit safety applications, locational accuracy is most critical as the bus approaches and traverses an instrumented intersection (PCW application), or enters a geo-fenced bus stop (VTRW application). Upon entering these areas, the GPS location can be used as a general basis and sensor weighting can be adjusted to allow more localized influence from the IMU data. IMU data error accumulation through these areas will be small.

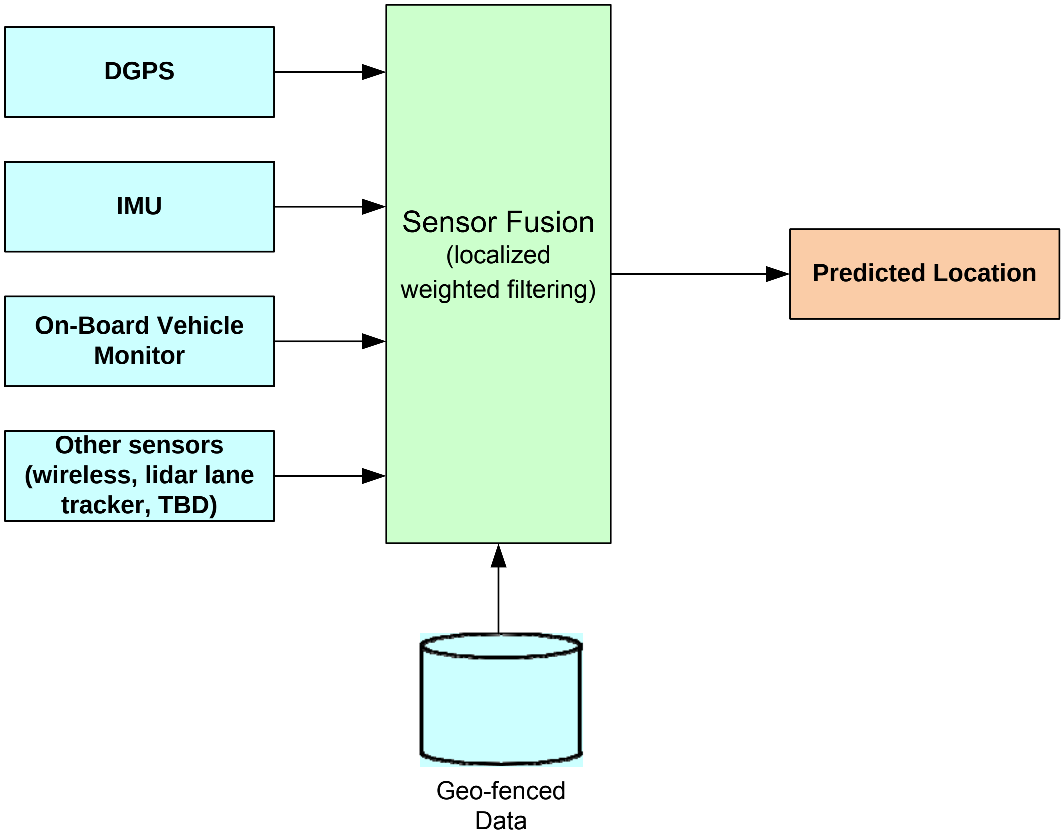
Similar to geo-fenced bus stops, regions with chronically poor GPS reception can be determined and defined. Persistently poor reception areas would generally be attributable to fixed geometrical conditions associated with multipath signal corruption or a low number of satellites leading to poor satellite geometry. Geo-fencing could not be used to define poor reception areas based on erratic ionospheric activity. Although commercial DSRCs report GPS signal quality, it often lags or does not consistently correlate with the magnitude of the GPS error. As the transit vehicle intersects these regions, the contributing weight of the IMU can be increased as part of the sensor fusion suite.

HV CAN Data

Vehicle CAN bus data is capable of providing information that can serve as another source of improving localized locational accuracy. Vehicle kinematics may be used in conjunction with a sideslip correction to provide an indication of incremental vehicle location. Like the IMU, locations predicted by CAN bus data have errors that tend to grow in time without bound. Employed as an added sensor and fused with the IMU and GPS data, HV CAN data is expected to add to the overall accuracy of the localized prediction of vehicle location.

Sensor Fusion

Figure 4-2 below summarizes the data flow from various locational sensors described above into a fusing and filtering application which will generate a more accurate locational prediction. This multi-sensor fusion approach may be extended to include other data sources.



Source: Battelle

Figure 4-2. Sensor Fusion Data Flow

Next Generation Pedestrian Detection

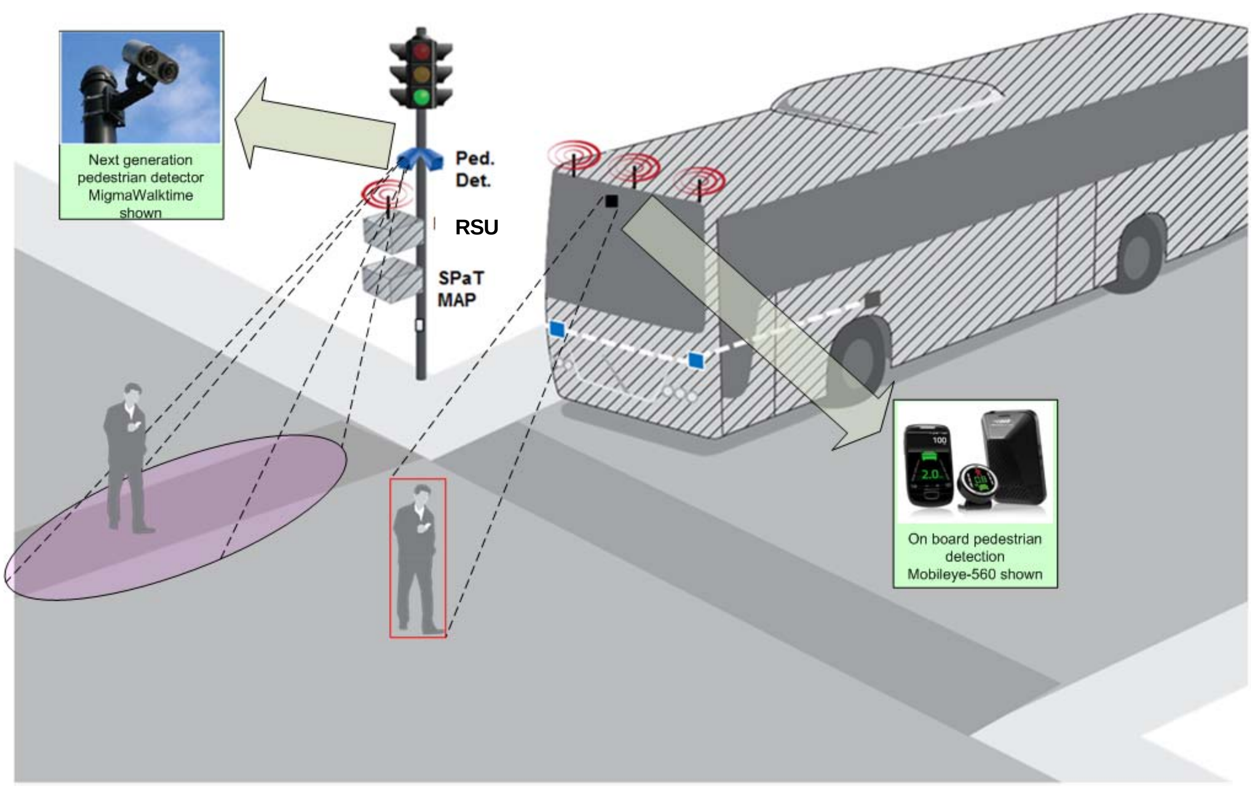
The next generation TRP will incorporate a pedestrian detector that leverages newly-emerging technologies and advances from commercial markets. Pedestrian (human) detection is a key focus area in computer vision with uses extending beyond automotive safety into robotics, surveillance and home entertainment systems. An example of in-home application is the popular Microsoft Kinect which combines visual and infrared (IR) sensors to detect human motion. Although Kinect technology is limited in range and operating environment, passive and active IR sensing is used as the basis for successful, in-vehicle Pedestrian Warning systems. Advanced microwave-radar, IR, video image processing, other emerging technologies and combinations of these techniques will be considered and an improved detection system will be deployed for the next generation TRP.

As examples of emerging products and technologies to consider, Econolite recently introduced a bicycle differentiation upgrade for its popular Autoscope product. The Autoscope product is also capable of detecting pedestrians in order to adjust pedestrian crossing time to accommodate slower pedestrians. FLIR System's C-Walk product provides an integrated video camera and sensor to detect pedestrians with Video Graphics Array (VGA) resolution at 25 frames/second. MigmaWalktime employs a high-resolution IR Light-emitting Diode (LED) stereo camera with on-board image processing to apply pedestrian detection algorithms using stereo vision analysis. GridSmart employs a single, high-resolution, fisheye camera with advanced tracking algorithms that can track and classify vehicles, and detect pedestrians.

Among the more interesting emerging approaches to pedestrian detection is the use of cellular Bluetooth or WiFi technologies to track pedestrian movement. This approach would be limited to pedestrians possessing and enabling Bluetooth or WiFi on their cell phones. However, the next generation TRP could deploy multiple Bluetooth TMSI sensors or WiFi access points (or WiFi Direct) with overlapping coverage zones within an intersection. The returned energy level would be triangulated to determine pedestrian location within the intersection. Another approach to leveraging personal hand-held devices would be to employ direct V2P communications where a smart phone with a BSM application would transmit a BSM over WiFi, which would in turn be received by the bus and used by a more generic V2P pedestrian warning application.

Pedestrian detection accuracy may also be extended through the use of on-board sensors. One example is the Mobileye 560 which was installed on the inside front windshield of the TRP transit vehicles and connected to the DAS. The TRP could use this device to detect front-facing RV range information. This device has the capability of detecting, recognizing and measuring the distance to both vehicles and pedestrians, and supports a Bluetooth interface that can communicate events to an external device. Aligning with the TRP mission to provide DSRC-based safety applications, a surrogate or proxy BSM message could be generated from the Mobileye output and be processed by the TRP through the established radio message data stream. This will allow the next generation TRP pedestrian detection to extend beyond instrumented intersections and would also detect pedestrians that stray outside of the crosswalks within instrumented intersections. Proxy BSM message generation could also alert DSRC-enabled vehicles in the vicinity to pedestrian locations.

Figure 4-3 illustrates a vision for the next generation TRP pedestrian detection.



Source: Battelle

Figure 4-3. Next Generation Pedestrian Detection

User Interface Enhancements

The next generation TRP would be built upon the results of a systematic Human Factors assessment to determine the appropriate TRP presentation within the bus driver workspace. The analysis would include an evaluation of the available real estate, and an evaluation of the way that the alerts are presented to the driver. The intent is to provide a seamless and optimal integration of the TRP safety alerts within the transit vehicle. One critical evaluation criterion for visual presentation alternatives would be the amount of screen real estate (pixels, physical dimension). For example, the Human Factors analysis result could suggest a change from an IVD to an in-dash LCD or a simple set of LED illuminators with aural cueing.

An alternative better suited to retrofit would be hosting the TRP alert presentation on existing Mobile Data Terminal (MDT) or Mobile Digital Computer (MDC) products. In this configuration, the miniWSU could be a peripheral to the MDT and the safety applications might be rehosted on the MDT. Candidate MDTs include products from Clever Devices, INIT Innovations in Transportation, Integrated Systems Research (ISR) Corporation and Trapeze Software Group. MDTs generally employ a Computer-Aided DiSPaTch/Automatic Vehicle Location (CAD/AVL) capability. Leveraging this information would provide TRP with knowledge of the intended bus route and could improve the quality of the PCW application (presumed lane going through intersection).

Repackaged and Ruggedized TRP Hardware

Challenges for the current TRP deployment include the power supply cable and the violation of safeguards built into the IVD battery charging system. The IVD power cable was periodically disconnected and reconnected to support data download. The vulnerability and wear of the exposed IVD power cable led to one incident of cable damage that defeated recharge and resulted in an inoperable IVD. The TRP IVD pauses charging when it detects that the battery temperature is too high. A protracted exposure of direct sunlight to the IVD back panel can cause a rise is battery compartment temperature sufficient to trigger the safeguard and pause battery charging. Positioned just inside of the front windshield, the IVD can have extended exposure to direct sunlight, especially during summer months. Consequently, the next generation TRP will depart from the IVD and move to a directly-powered, permanently attached power and data cable for data display.

The TRP package will decrease in size and be relocated to the overhead compartment immediately behind the driver. With the incorporation of a simple output display, the Moxa wireless network, 5V DC/DC converter, and the associated Ethernet connection is obviated. The package may be reduced in size to include the DSRC, power handling/conditioning devices and an optional small Ethernet switch to facilitate DAS connectivity.

Software Enhancements

The TRP miniWSU experienced periodic resets where an internal software monitoring task detected that one of the TRP software tasks failed to meet a processing deadline. In response, the complete set of support tasks were killed and restarted by the monitor task. The reset action is thought to be related to CPU starvation and requires approximately 20 seconds to accomplish. During this window, all safety and transit applications are disabled while the miniWSU recovers.   In the next generation TRP, the root cause of the miniWSU reset within the firmware will be determined and resolved.

The next generation PCW application will be improved. The distance that PCW is active from the intersection will be decreased which will reduce nuisance alerts and provide driver notifications at a time and place when most effective in avoiding collisions. Inclusion of HV velocity will be included to predict and further restrict PCW alerts to appropriate circumstances. The use of proxy BSMs from MobileEye will expand PCW to a larger area of application beyond the defined crosswalk areas of instrumented intersections, and to faster moving joggers and bicyclists.

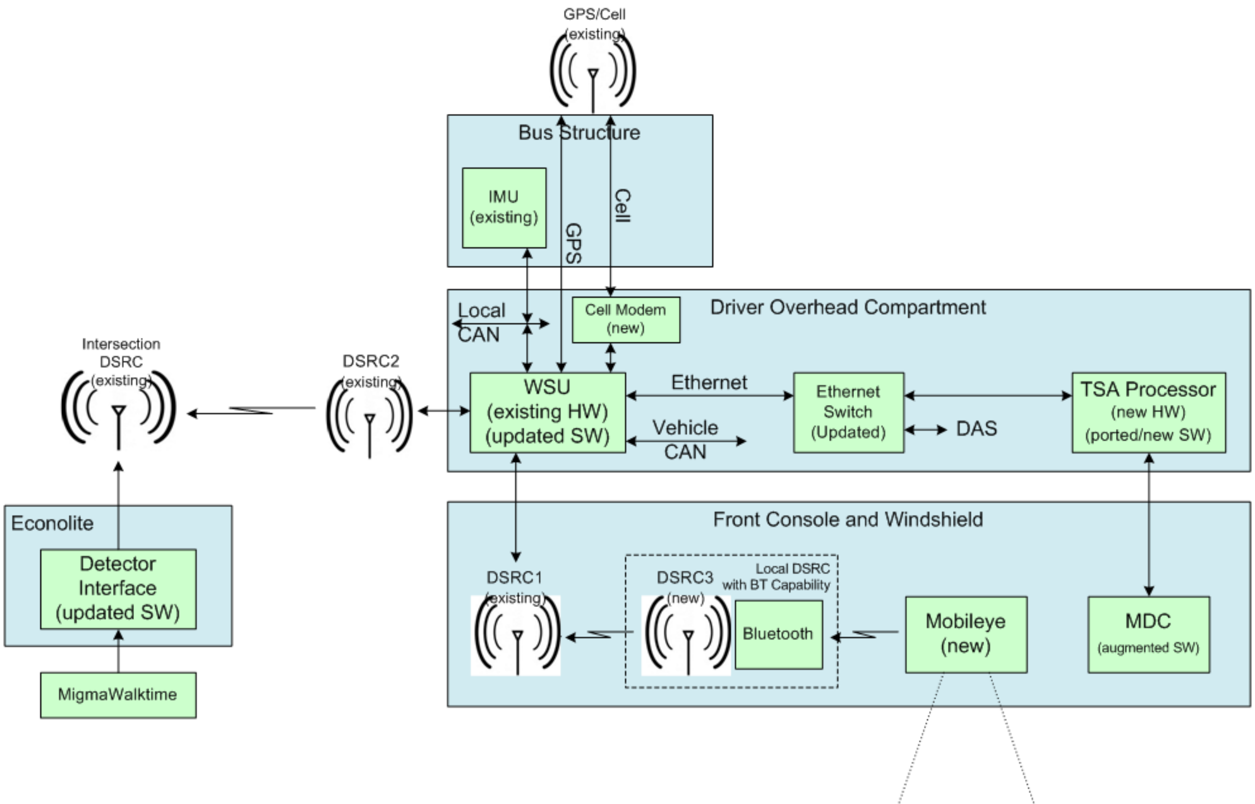
The next generation VTRW application will be improved. Overall target classification performance will be made better from the increased DGPS locational accuracy. The algorithm will be modified to reduce nuisance alerts where there's not imminent danger through analysis of vehicle position and velocity with respect to the relative position and velocity of the RV. Within a bus stop, the geo-fenced definitions will be enhanced to include a traffic direction vector. The VTRW will use the direction vector to orient and normalize the target classification grid. This will avoid target classification errors due to orientation fluxuation as the transit vehicle slows and stops within the bus stop. VTRW coverage can also be expanded for operation outside of the boundaries of the limited set of geo-fenced bus stops for more generic collision avoidance.

Next Generation TRP Summary

The architecture of a candidate next generation TRP system is summarized in this section. For development efficiency, the architecture builds from the current TRP architecture. The design represents a selected combination of the above ideas:

- GPS accuracy enhancements:
    - Cellular network antenna and transceiver for communication with the CORS network. The TRP transit vehicles are currently equipped with a cell antenna and routing cable.
    - A cellular modem that communicates RTCM/NTRIP network data. This will interface the correction factors to the GPS receiver.
    - Routing of IMU data through the local CAN bus to the WSU
- Re-host of TRP Transit Safety Applications (TSAs) to the host DSRC (miniWSU), to a separate TSA processor, or to the MDC which would host the transit safety applications. A separate TSA processor is shown in the figure below.
- A Mobileye pedestrian detector will be incorporated that will communicate detections to a DSRC via Bluetooth. This new DSRC will broadcast proxy BSMs that will be received by the existing DSRC and passed to the WSU and TSA processor for use by the PCW safety application.
    - Alternatively, a Bluetooth USB adapter could be used to interface directly with the DENSO WSU
- The DENSO WSU software will be updated to eliminate the reset, interface to the IMU and cell, and implement the GPS accuracy filtering.
- The MDC will display the basic and transit safety application alerts.
    - This is conditional to the outcome of the Human Factors study and ease of adding custom software to MDCs.
- The pedestrian detector software contained within the Econolite master controller cabinet will be updated to interface with the MigmaWalktime detectors.

Figure 4-4 provides a summary of the Next Generation TRP system architecture.



Source: Battelle

Figure 4-4. Next Generation TRP Architecture Summary

Appendix A Terms and Abbreviations

Acronyms and Abbreviations

ASD	Aftermarket Safety Device
BSM	Basic Safety Message
CAD/AVL	Computer-Aided Dispatch/Automatic Vehicle Location
CAN	Controller-Area Network
CCV-RSD	Connected Commercial Vehicle – Retrofit Safety Device
CONOPS	Concept of Operations
COTA	Central Ohio Transit Authority
COTS	Commercial-off-the-shelf
CPU	Central Processing Unit
CSW	Curve Speed Warning
CORS	Continuously Operating Reference Station
CV	Connected Vehicle
DAS	Data Acquisition System
DGPS	Differential GPS
DSRC	Dedicated Short-Range Communication
EEBL	Emergency Electronic Brake Light
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GPS	Global Positioning System
HV	Host Vehicle
IE	Independent Evaluator
IEEE	Institute of Electrical and Electronics Engineers
IMU	Inertial Measurement Unit
IR	Infrared

IRB	Institutional Review Board
ISTEA	Intermodal Surface Transportation Efficiency Act
ITS	Intelligent Transportation System
IVI	Intelligent Vehicle Initiative
JPO	Joint Program Office
KPH	Kilometers Per Hour
LAN	Local Area Network
LCD	Liquid-crystal Display
LED	Light-emitting Diode
MAC	Medium Access Control
MAP	Geometric Intersection Description (MAP-SAE J2735)
MDC	Mobile Digital Computer
MDT	Mobile Data Terminal
MPH	Miles Per Hour
NHTSA	National Highway Traffic Safety Administration
OBE	On-Board Equipment
OS	Operating System
PCAP	Packet Capture
PCW	Pedestrian in Signalized Crosswalk Warning
PHY	Physical Layer
RSD	Retrofit Safety Device
RSE	Roadside Equipment
RSSI	Received Signal Strength Indicator
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
RTV	Room Temperature Vulcanizing silicone
RV	Remote Vehicle
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing
TCP/IP	Transmission Control Protocol/Internet Protocol
TEA-21	Transportation Equity Act for the 21st Century

TIM	Traveler Information Message
TRP	Transit Safety Retrofit Package
TSA	Transit Safety Applications
UDP	User Datagram Protocol
UM Transit	University of Michigan Transit
UMTRI	University of Michigan Transportation Research Institute
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
VAD	Vehicle Awareness Device
VGA	Video Graphics Array
VTRW	Vehicle Turning Right in Front of Bus Warning
WAAS	Wide Area Augmentation System
WAVE	Wireless Access in Vehicular Environments
WSU	Wireless Safety Unit

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