Transit Safety Retrofit Package Development

Architecture and Design Specifications

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16. Abstract

The Architecture and Design Specifications capture the TRP system architecture and design that fulfills the technical objectives stated in the TRP requirements document.

The document begins with an architectural overview that identifies and describes the top-level components of the system and describes how those components interface with critical internal and external elements. The architectural description is followed by a system design description that provides a detailed examination of the architectural components. The design description includes:

- A hardware and software overview
- A description of TRP inputs and outputs
- A detailed description at each of the architectural components
- A description of the external roadside equipment (RSE) that interfaces with the TRP

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D	5/19/2014	Incorporated review comments received from USDOT	All

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Chapter 1 Scope

This Architecture and Design Specification for the Transit Safety Retrofit Package Development (TRP) captures the architecture and design towards fulfilling the technical objectives as stated in Contract No. DTFH61-12-C-00007.

Chapter 2 Applicable 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 J551	Vehicle Electromagnetic Immunity--Off-Vehicle Source, SAE International
SAE J1113	Conducted Immunity, 250 kHz to 400 MHz, Direct Injection of Radio Frequency (RF) Power, SAE International
SAE J1939	Serial Control and Communications Heavy Duty Vehicle Network, SAE International
SAE J2735	Dedicated Short-Range Communications (DSRC) Message Set Dictionary, SAE International

International Organization for Standards

ISO 15765-4:2011	Road vehicles – Diagnostic communication over Controller Area Network (DoCAN) – Part 4: Requirements for emissions-related systems

U.S. Department of Transportation

DOT HS 811 492A	Vehicle Safety Communications –Applications (VSC-A), Final Report, September 2011

Denso International America

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

MS SEDCO

	SmartWalk™ XP Installation Manual, Version XPv0209

University of Michigan Transportation Research Institute

TRP DAS	Transit Safety Retrofit Package (TRP): Data Acquisition System (DAS) Documentation, July 17,2013

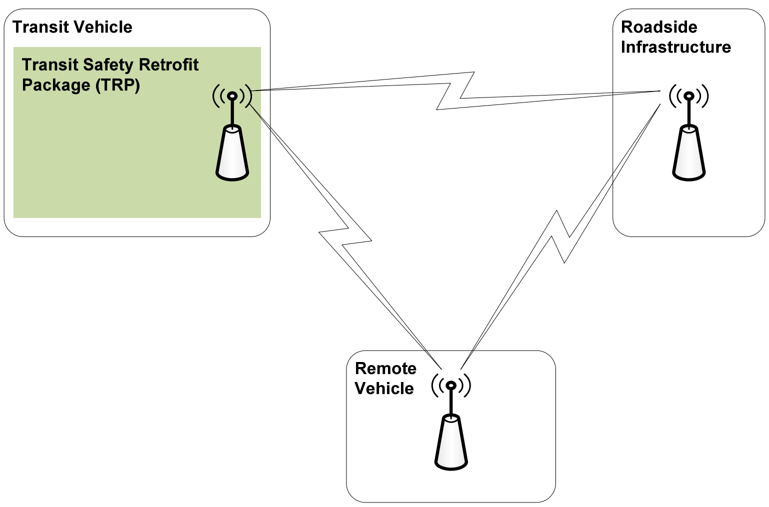
Battelle Drawings/Documents

100008379-0001	Transit Safety Retrofit Package (TRP) Concept of Operations (CONOPS)
60606-018A	Interface Control Document for the Signal Phase and Timing and Related Messages for V-I Applications,
100008379-0004	Transit Safety Retrofit Package Development Applications Requirements Document

Chapter 3 System Overview

System Overview and Context

The system-of-interest for TRP Development is a demonstration system where three transit buses are equipped with retrofit connected vehicle safety packages, including two new transit safety applications. The buses participated as "retrofitted" vehicles in the Safety Pilot Model Deployment in Ann Arbor, Michigan and support further research beyond the deployment. How the system-of-interest fits into the overall system context and its physical and interface boundary are illustrated in Figure 3-1.



Source: Battelle

Figure 3-1. System of Interest

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

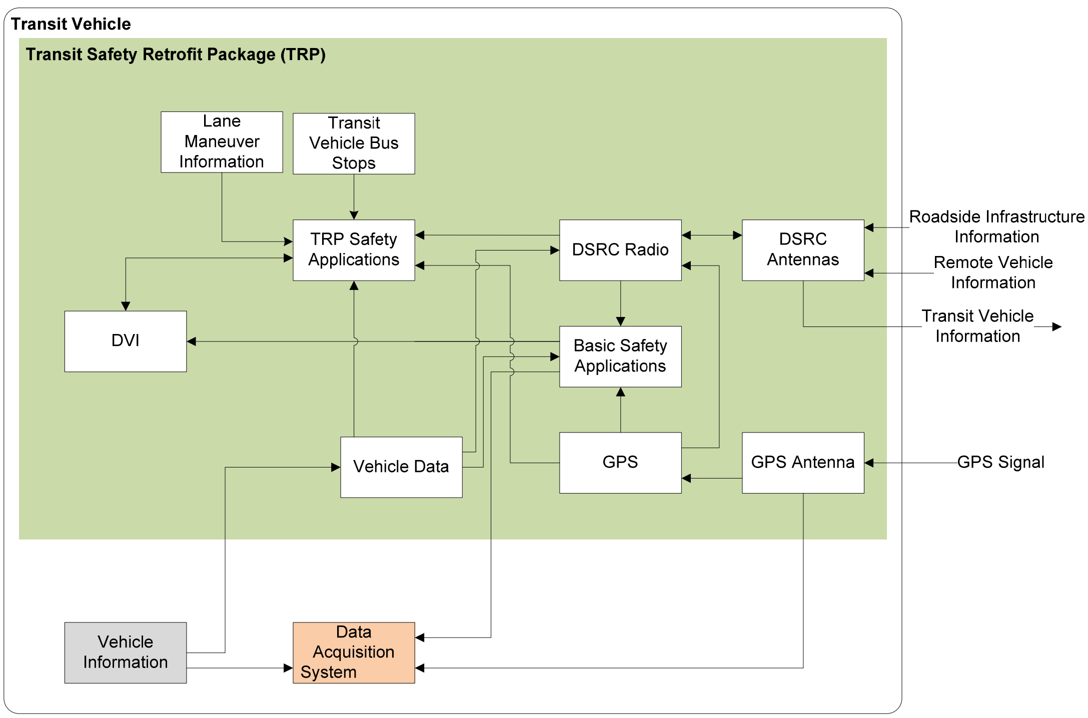
Using J2735 Basic Safety Messages received from other Safety Pilot Model Deployment Remote Vehicles, and Signal Phase and Timing and MAP messages from Roadside Equipment along with on-board Transit Vehicle information received from an on-board data bus and sensors installed specifically for the test, the TRP provides five safety applications broken down into two categories – TRP Safety Applications and Basic Safety Applications. The TRP Safety Applications include Pedestrian at Crosswalk Warning (PCW) and Vehicle Turning Right Warning (VTRW). Basic Safety Applications include Curve Speed Warning (CSW), Emergency Electronic Brake Light (EEBL), and Forward Collision Warning (FCW).

A more descriptive overview of the TRP System is described in the TRP CONOPS document (100008379-0001).

Chapter 4 TRP Architecture

Architecture Overview

A high level architectural view of the TRP is shown in Figure 4-1. Roadside Infrastructure Information, Remote Vehicle Information and Global Positioning System (GPS) Signals are external inputs to TRP. The Roadside Infrastructure Information and Remote Vehicle Information inputs are received by a DSRC Radio component and the GPS Signal is received by a GPS Receiver component.



Source: Battelle

Figure 4-1. TRP Architecture

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

Components to TRP include DSRC Radio, DSRC Antennas, GPS Receiver, GPS Antenna, Vehicle Data Interface, a Driver Vehicle Interface (DVI), Bus Stop Location Data, PCW Lane Maneuver Information[1], the TRP Safety Applications, and the Basic Safety Applications.

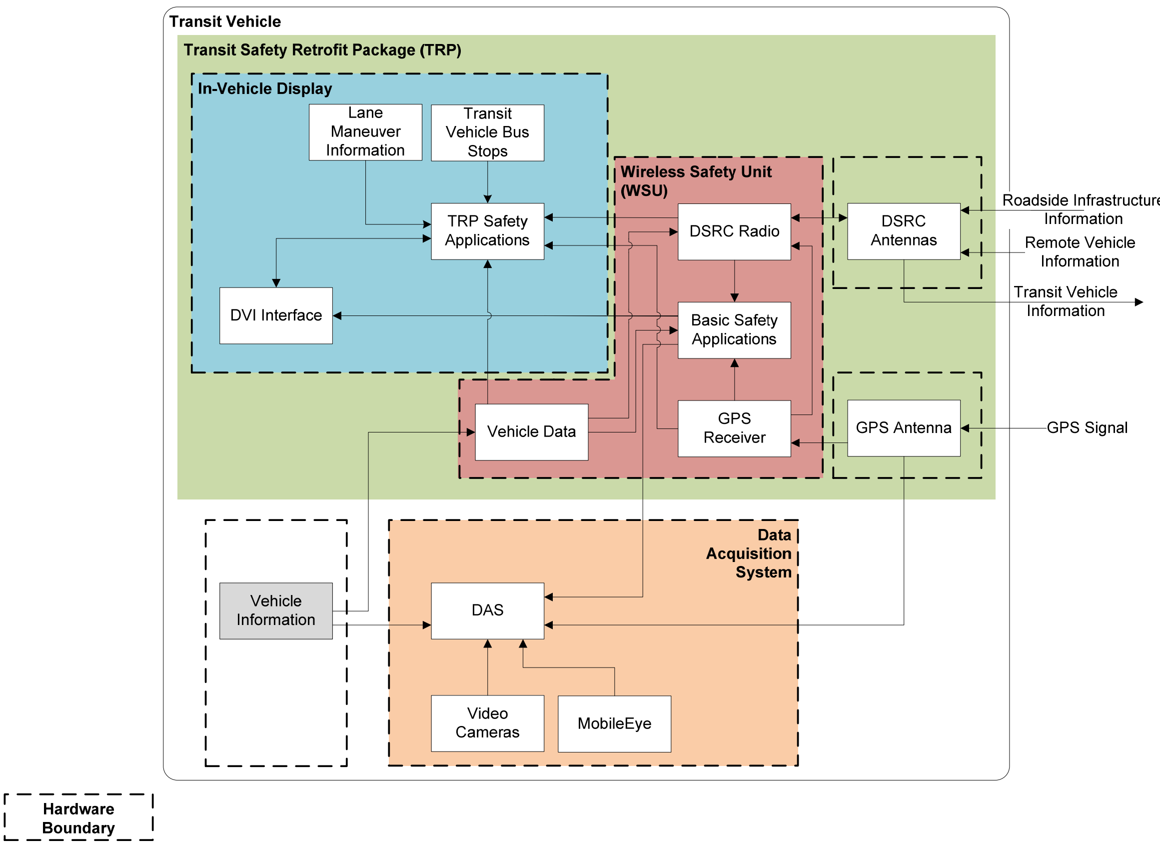
A Data Acquisition System (DAS), which is not part of TRP, is included as supporting equipment in order to record events and data during the period that the TRP is deployed for the Safety Pilot Model Deployment.

[1] 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.

Chapter 5 TRP Design

Design Overview

After performing functional analysis on the TRP Architecture shown above in Figure 4-1, functional decomposition of the TRP was performed to identify appropriate hardware boundaries. Figure 5-1 is the result of the functional decomposition.



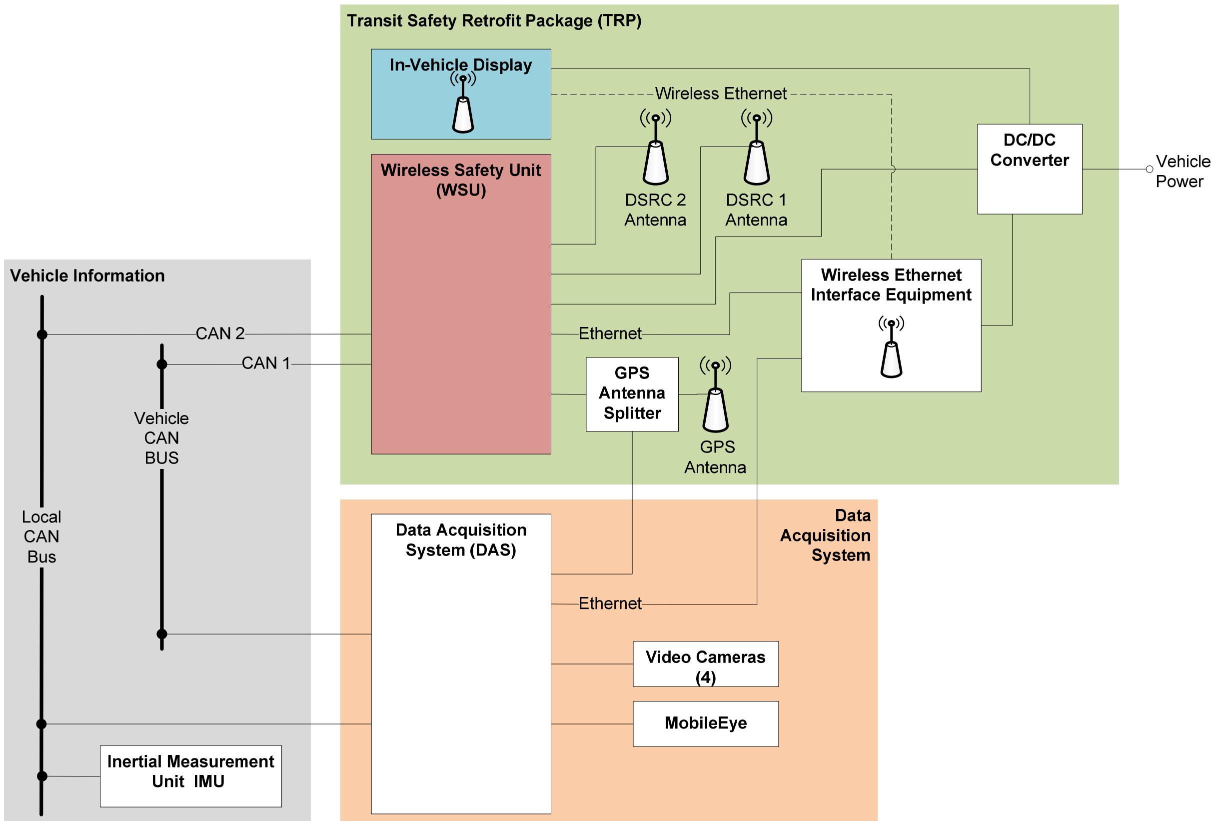
Source: Battelle

Figure 5-1. Functional Decomposition

The hardware boundaries were selected based on grouping functions that were easily combined together into one unit. Hardware boundaries may include multiple hardware components. As a result, the TRP was broken out into an In-Vehicle Display, Wireless Safety Unit (WSU), DSRC Antennas, and GPS Antenna. The TRP supporting equipment was broken out into Vehicle Information and Data Acquisition System.

Hardware Overview

A hardware block diagram for the TRP and supporting equipment is shown in Figure 5-2. This figure identifies the main components and the associated interconnections that are required.



Source: Battelle

Figure 5-2. Hardware Block Diagram

List of Hardware Includes:

- TRP
  - In-Vehicle Display
  - Wireless Safety Unit (DENSO miniWSU)
  - DSRC Antenna 1 and DSRC Antenna 2
  - GPS Antenna and GPS Antenna Splitter
  - Wireless Ethernet Interface Equipment (Ethernet Switch, Wireless Access Point)
  - DC/DC Converter
- Supporting Equipment
  - Data Acquisition System
    - o DAS
    - o Video Cameras
    - o MobileEye (optical ranging device)

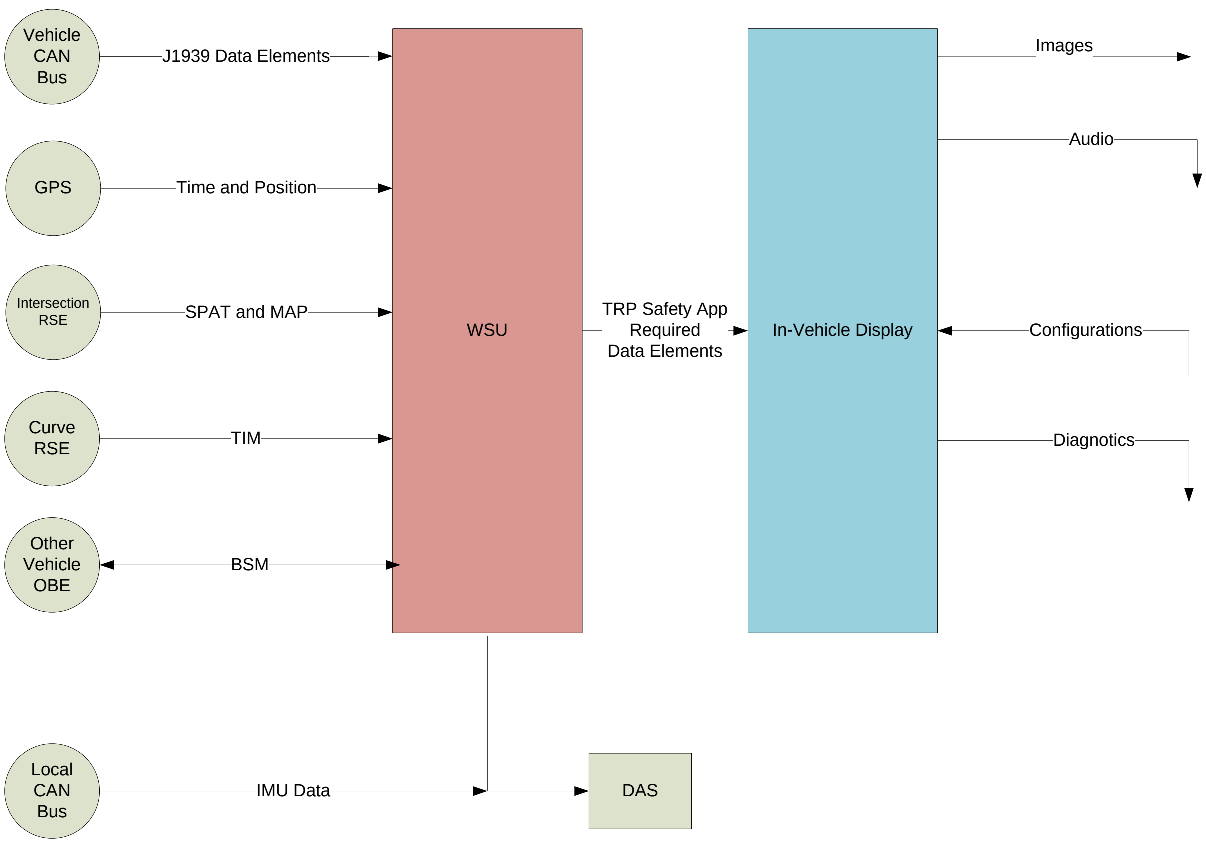
- Vehicle Information
  - Interface to Existing Vehicle CAN Bus
  - Local CAN Bus – IMU

A more in depth description of each component is described in the TRP Equipment section of this document.

Software Overview

The software for the TRP system addresses three key needs. The first is to integrate three safety applications being developed for the Connected Commercial Vehicle – Retrofit Safety Device (CCV-RSD) project into the TRP demonstration system (FCW, EEBL, CSW). The second is to develop two new transit safety applications to be added to the TRP platform, Vehicle Turning Right and Pedestrian at Crosswalk Warning. The final key need addressed by the software is to provide data about the operation of all five safety applications for the independent evaluator of the safety pilot field test.

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



Source: Battelle

Figure 5-3. TRP Software Block Diagram

TRP Inputs and Outputs

The data inputs and outputs to the TRP system can be divided into four main types. The first is data transmitted via DSRC radio, such as Basic Safety Messages (BSM) and Signal Phase and Timing (SPAT) Messages. 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. 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. 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.

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 available in Table 5-1 below.

Table 5-1. 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				

Source: Battelle

TRP Equipment

This section contains a detailed description of each piece of equipment that is either installed or modified to support the TRP in the transit vehicle. All hardware components associated with the TRP system are commercial-off-the-shelf (COTS) products. The Electromagnetic Immunity and Conducted Immunity of the components meet the standards set for the mobile equipment community, but no specific documentation of compliance with SAE J551 or SAE J1113 have been provided or verified. Software development details for each component that required new software or updates to existing software are described under the corresponding TRP equipment.

In-Vehicle Display

The In-Vehicle Display is provided by Battelle. The In-Vehicle Display provides aural and visual indication of the five safety applications warnings. The In-Vehicle Display provides the computations for the two new safety applications – Pedestrian at Crosswalk Warning and Vehicle Turning Right Warning.

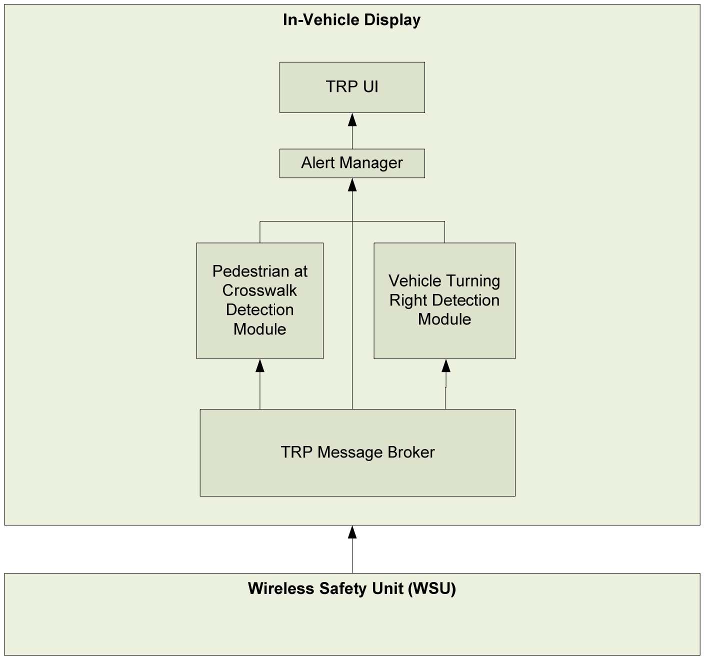
Hardware

The In-Vehicle Display is a Samsung Galaxy Tab™ computer. This item is a commercial-off-the-shelf (COTS) product. The tablet computer is equipped with IEEE 802.11 a/b/g/n Wi-Fi® and Bluetooth to support communications with the WSU and provides the means to display visual and aural alerts to the Transit Vehicle driver. The mounting of the In-Vehicle Display allows the Transit Vehicle driver to view the display while not obstructing the Transit Vehicle driver's field of view.

Software

Software developed for the In-Vehicle Display is based on the Android™ OS. The high level software block diagram is shown in Figure 5-4. 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 Display Module and the User Interface. The following system activities are addressed by the software on the In-Vehicle Display:

- Receive alerts from CSW, FCW and EEBL apps residing on the WSU and display appropriate signage to the driver
- Receive and parse SPAT and MAP Message Blob payload data and determine if an alert condition exists and display appropriate Pedestrian at Crosswalk signage to the driver
- Receive and parse Remote Vehicle Position and Heading, and Target Classification data to determine if a Vehicle Turning Right alert condition exists and display appropriate signage to the driver



Source: Battelle

Figure 5-4. In-Vehicle Display High Level Software Block Diagram

TRP Message Broker

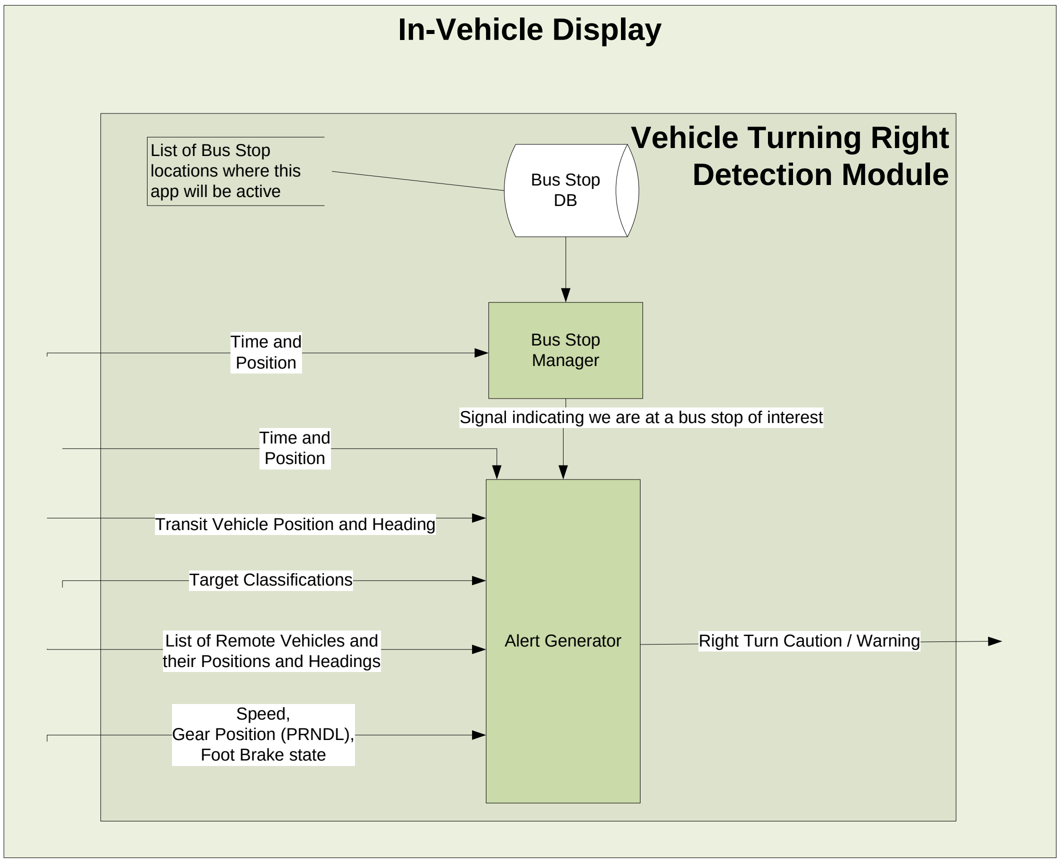
The TRP Message Broker module communicates with the WSU to receive the following information.

- Transit Vehicle's current global positioning system (GPS) position and time
- Transit Vehicle's speed
- Transit Vehicle's gear position
- Transit Vehicle's foot brake status
- Remote vehicle(s) position
- Remote vehicle(s) 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
- CSW Alert Status
- EEBL Alert Status
- FCW Alert Status

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

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 5-5.



Source: Battelle

Figure 5-5. Vehicle Turning Right Detection High Level Software Block Diagram

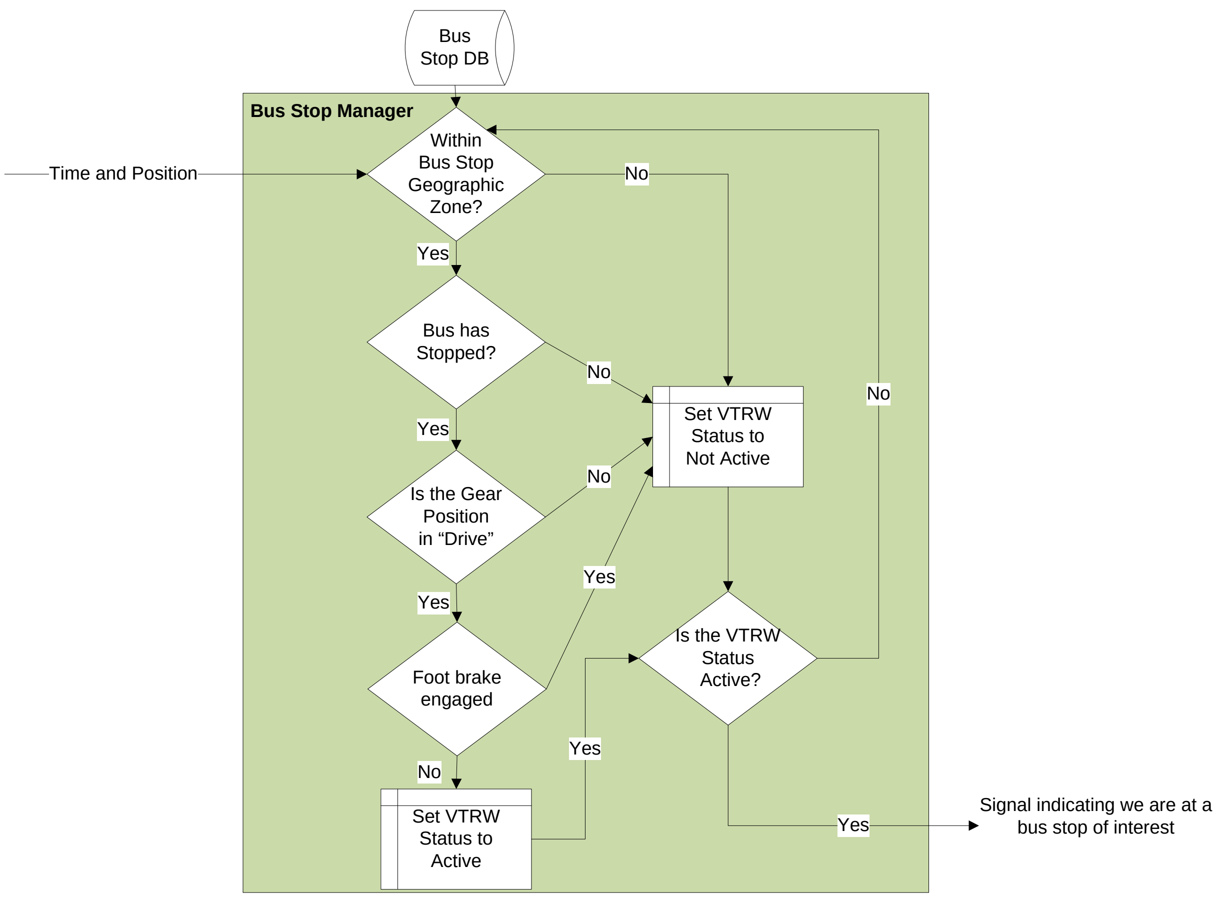
Bus Stop locations for the Transit Vehicle route are stored within the module for determination that the Transit Vehicle is within proximity of a Bus Stop. The criteria for determining that the Transit Vehicle is within the proximity of the Bus Stop are based on the GPS location of the Transit Vehicle. 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) path history
- Remote vehicle(s) target classification

The 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 5-6 shows a flowchart of the logic to determine when to trigger the Vehicle Turning Right Detection module to become active.



Source: Battelle

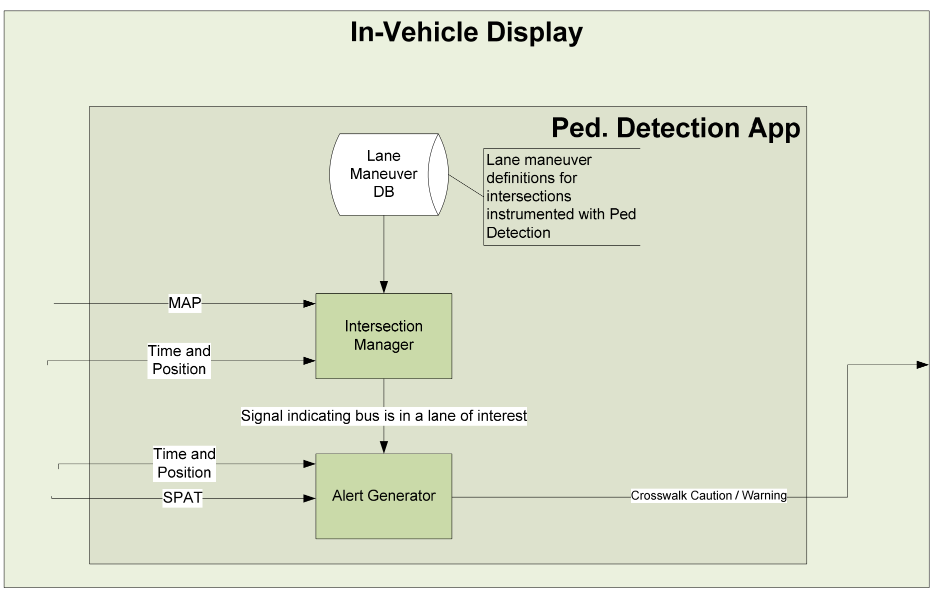
Figure 5-6. Vehicle Turning Right Bus Stop Manager Flowchart

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 the Path History, Path Prediction and Target Classification. The Target Classification provides a relative classification of the locations of communicating 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 Display Module 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 is departing 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. Details for the specific conditions and thresholds for generating an Inform or Warning Alert are described as operational scenarios in the TRP CONOPS document (100008379-0001).

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 5-7.



Source: Battelle

Figure 5-7. Pedestrian at Crosswalk Detection High Level Software Block Diagram

Lane maneuver information for the intersections that are equipped with the properly configured Signal Controller and Signal Phase and Timing (SPAT) interface device are stored within a datastore within the module.

The Pedestrian at Crosswalk Decision 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 MAP message data
  - 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

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 Display Module 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 predicted 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. Details for the specific conditions and thresholds for generating an Inform or Warning Alert are described as operational scenarios in the TRP CONOPS document (100008379-0001).

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 TRP Safety Applications Alert Levels are shown in Table 5-2.

Table 5-2. TRP Safety Applications 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 pedestrian in crosswalk.	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 TRP Safety Applications are described in Table 5-3.

Table 5-3. TRP Safety Applications Aural Alert

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 In-Vehicle Display. The Message Broker passes this information to the Alert Manager. The Basic Safety Applications Alert Levels are described in
Table 5-4. Table 5-4 is a copy of Table 4-1 of the Denso ASD User’s Guide.

Table 5-4. Basic Safety Applications Alert Levels (Table 4-1 of Denso ASD User’s Guide)

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: Battelle

When a Basic Safety Application alert occurs, a verbal description of the alert condition is generated by the DVI. Additionally, when a Basic Safety Applications alert occurs, a unique visual alert for an inform alert and warning alert is presented. Aural Alerts for the Basic Safety Applications are described
Table 5-5.

Table 5-5. TRP Safety Applications Aural Alert

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

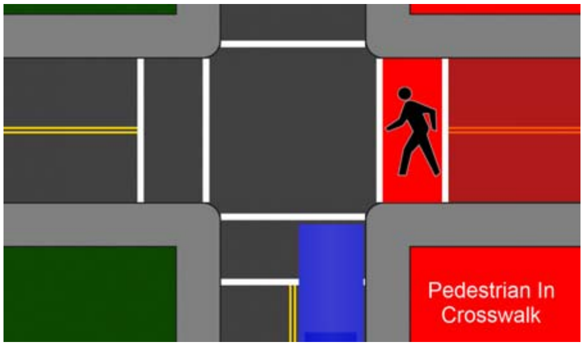
The TRP Safety Applications are focused on the situation where the Transit Vehicle is stopped, accelerating from a stop, or turning at a signalized intersection; the Transit Vehicle is typically at a lower rate of speed. The Basic Safety Applications are typically geared toward alerting the Transit Vehicle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

The display of TRP Safety Applications is contained in a later paragraph. The Alert Display Module accommodates the display of a Pedestrian at Crosswalk alert or a Vehicle Turning Right 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.

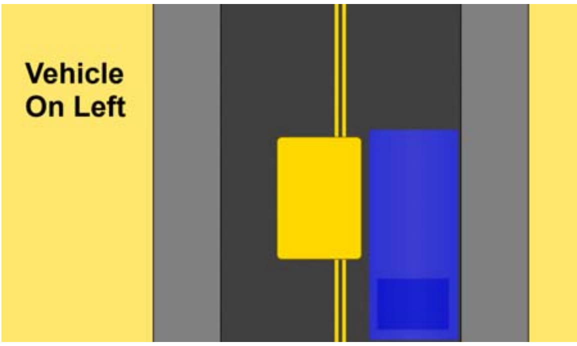
User Interface

The User Interface depicts the appropriate display for the Transit Vehicle driver depending on if an alert is present. The following figures (Figure 5-8 through Figure 5-12) depict a set of sample screens that the In-Vehicle Display may depict to the Transit Vehicle driver. Not all permutations are shown.



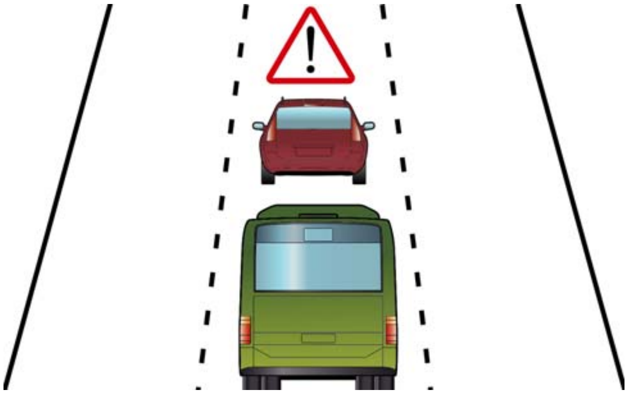
Source: Battelle

Figure 5-8. Pedestrian at Crosswalk Warning Preliminary Display Screen



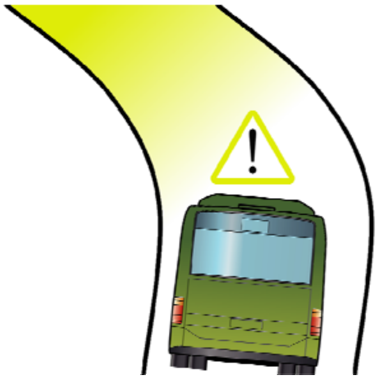
Source: Battelle

Figure 5-9. Vehicle Turning Right Inform Preliminary Display Screen



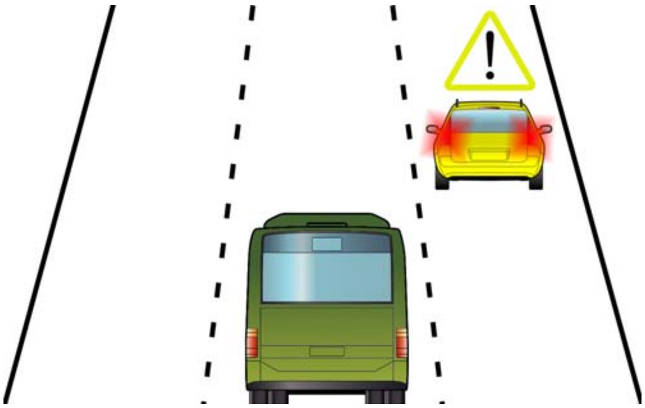
Source: Battelle

Figure 5-10. FCW Warning Preliminary Display Screen



Source: Battelle

Figure 5-11. CSW Approach Inform Preliminary Display Screen



Source: Battelle

Figure 5-12. EEBL Inform Preliminary Display Screen

When there is no alert present, but the TRP is active, a default screen is presented to provide indication to the Transit Vehicle driver that the system is active and operational. The default screen is shown in Figure 5-13.

Source: Battelle

Figure 5-13. In-Vehicle Display Default Screen

Wireless Safety Unit (WSU)

The WSU is provided by Battelle subcontractor, DENSO. 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 In-Vehicle Display, DAS, and the DSRC Antennas. This unit is viewed as a COTS item which has software additions included to support the TRP Safety Applications and the display of alerts.

Hardware

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. The miniWSU device incorporates a custom computing platform, GPS positioning receiver, and specialized communications interfaces.

Externally mounted GPS and DSRC radio antennas are used to support receiving GPS Signals and bidirectional communications on the DSRC radio.

Software

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. Additionally, the three safety applications provided by DENSO include CSW, EEBL, FCW are preloaded. The safety applications determine when a visual and aural alert is needed and communicates the appropriate information to the In-Vehicle Display for providing the user interface for the alert as described in the In-Vehicle Display software description section of this document.

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 In-Vehicle Display

- Transit Vehicle's current GPS position and time
- Transit Vehicle's speed
- Transit Vehicle's gear position
- Transit Vehicle's foot brake status
- Intersection SPAT Message Blob payload data
  - Crosswalk phase of particular crosswalk
  - Pedestrian detected in crosswalk and identifier of particular crosswalk
- Intersection MAP
  - Intersection Reference ID
- Remote vehicle(s) position and heading
- Remote vehicle(s) target classification

- CSW Alert Status
- EEBL Alert Status
- FCW Alert Status

The WSU transmits the following information on the DSRC Radio.

- SAE J2735 Basic Safety Message (BSM) approximately once every 100 milliseconds.

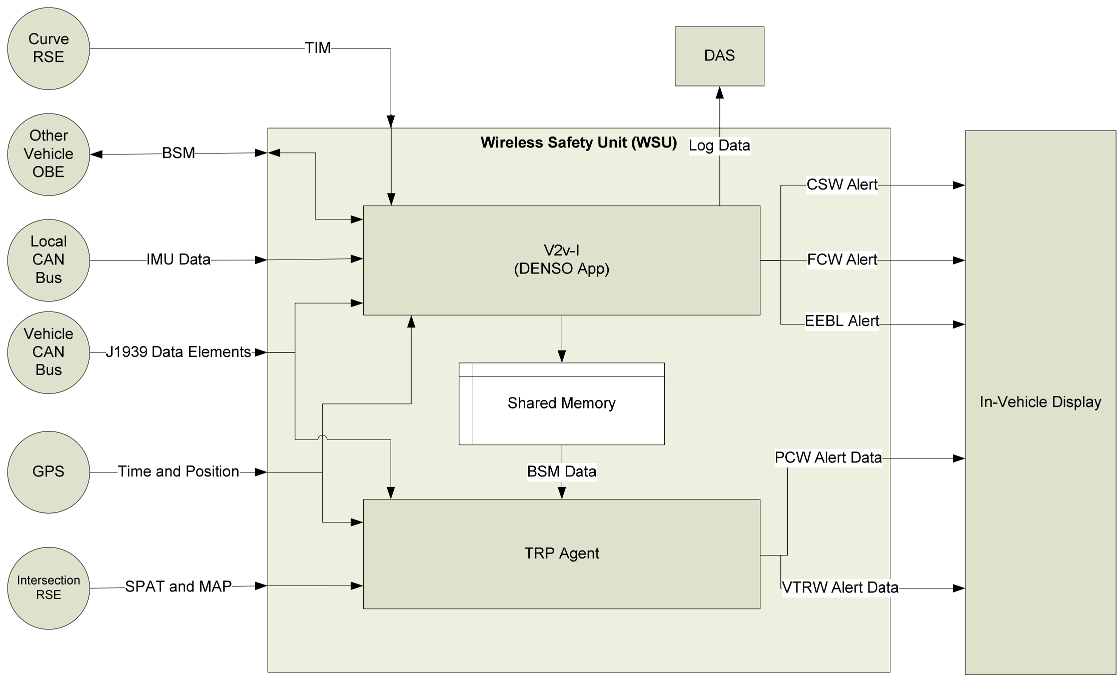
CSW aids drivers in negotiating curves at appropriate speeds. This application uses information communicated from an RSU located ahead of approaching curves. The communicated information from the RSU would include curve location, curve speed limits, curvature, bank, and road surface condition. The device 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 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).

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.

The Alert Arbitrator prioritizes the alerts detected by CSW, EEBL, and FCW and determines which alert to notify the In-Vehicle Display for creating a visual and aural alert.

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 TRP 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 In-Vehicle Display. As illustrated in Figure 5-14, the two main applications running on the WSU are the v2v-i and TRP Agent.



Source: Battelle

Figure 5-14. WSU Software Block Diagram

The v2v-i application delivered with the WSU provides an initial set of features and functionality. This application receives as inputs DSRC radio messages, GPS data and CAN data and after processing that data provide additional information as outputs. Those outputs are alert information from the three safety applications (CSW, FCW and EEBL), Remote Vehicle BSM data stored into Shared Memory and log data for use by the DAS. Below is a table (Table 5-6) which summarizes the inputs and outputs of the v2v-i application of interest to the TRP platform.

Table 5-6. Inputs/Outputs for v2v-i Applications

Data Element	Input/Output	Purpose
TIM	Input	Used by the CSW Application
BSM	Input and Output	Used by FCW and EEBL and stored in Shared Memory
Transit Vehicle CAN data	Input	Used by CSW, FCW and EEBL
GPS	Input	Used by CSW, FCW and EEBL

Source: Battelle

The TRP Agent is a new piece of software which was developed to support the two new Transit Safety applications being developed under this contract. The information needed to perform the Vehicle Turning Right Warning application and the Pedestrian at Crosswalk Warning application are gathered by the TRP Agent and forwarded to the In-Vehicle Display platform for processing. In order to minimize the dependency on any single WSU radio type, a minimal amount of processing and analysis of the data is performed in the TRP Agent. Data elements being received as input and provided as output to other systems by the TRP Agent are detailed in Table 5-7 below:

Table 5-7. Data Elements Passed by the TRP Agent to the In-Vehicle Display

Data Element	Input/Output	Purpose
SPAT	Input and Output	SPAT Message Blob payload data relayed to In-Vehicle Display for further processing
MAP	Input and Output	MAP Message Blob payload data relayed to In-Vehicle Display for further processing
Transit Vehicle CAN data (gear position, brake status and speed)	Input and Output	Relayed to In-Vehicle Display for further processing
GPS	Input and Output	Relayed to In-Vehicle Display for further processing

Source: Battelle

Since the Data Acquisition System (DAS) was not available while some of the TRP components were placed into operations, the TRP provided some level of data storage during the time period when the TRP was installed prior to the DAS being integrated. The following data was stored within the In-Vehicle Display:

1) GPS Data (once per second)
    a. Availability
    b. Elevation
    c. GPS Heading
    d. GPS Position Accuracy
    e. GPS Speed
    f. GPS Time
    g. Latitude
    h. Longitude
    i. Number of Satellites
2) Vehicle Data Associated with the Applications (once per second)
    a. Brake pedal activation
    b. Speed
    c. Throttle position
    d. Foot brake status
    e. Transmission State
3) Application Data (Event Based)
    a. EEBL Application Active
    b. EEBL Threat Detected
    c. EEBL Inform Message Displayed on GUI
    d. EEBL Warning Message Displayed on GUI
    e. FCW Application Active
    f. FCW Threat Detected
    g. FCW Inform Message Displayed on GUI
    h. FCW Warning Message Displayed on GUI
    i. CSW Application Active

   j. CSW Threat Detected
   k. CSW Inform Message Displayed on GUI
   l. CSW Warning Message Displayed on GUI

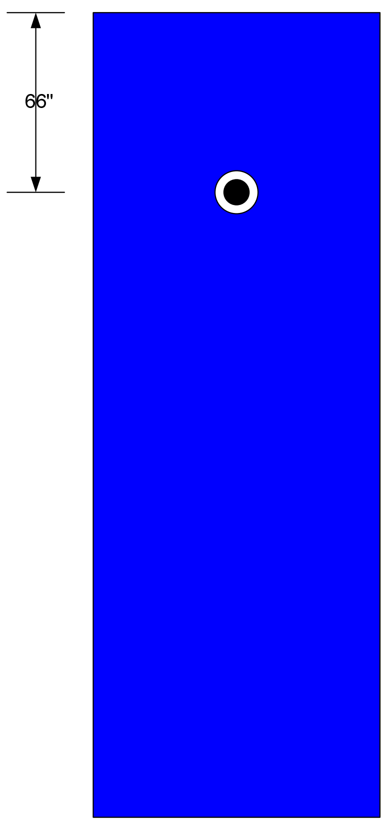
4) Primary Keys associated for all data elements listed above
   a. Device ID (Fixed BSM bytes)
   b. Time (Deci-seconds)
   c. Trip ID

Wireless Ethernet Interface Equipment

There is an Ethernet switch (Moxa PN: EDS-205A-T, or similar) and a Wireless Access Point (AP) (Moxa PN: AWK-3121-US-T, or similar) installed on the transit vehicle. This allows both wireless and wired Ethernet connections to a local network on the transit vehicle.

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 (Mini-Circuits PN: ZAPD-2DC-S+) is used to split the antenna signal to allow both TRP and DAS access to a GPS antenna. Getting an external GPS antenna mounted poses a challenge. A hole was created for the GPS 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 Room Temperature Vulcanizing silicone (RTV) was placed between the ground plane and the bus, as well as between the GPS antenna and ground plane. Once the antenna was mounted, a layer of white RTV was placed around the ground plane. The GPS antenna was located 66" from the front of the bus and centered in reference to the sides. A graphic showing the position of the antenna on the roof of the bus is portrayed in Figure 5-15.



Source: Battelle

Figure 5-15. GPS and Cell Cable Hole Location

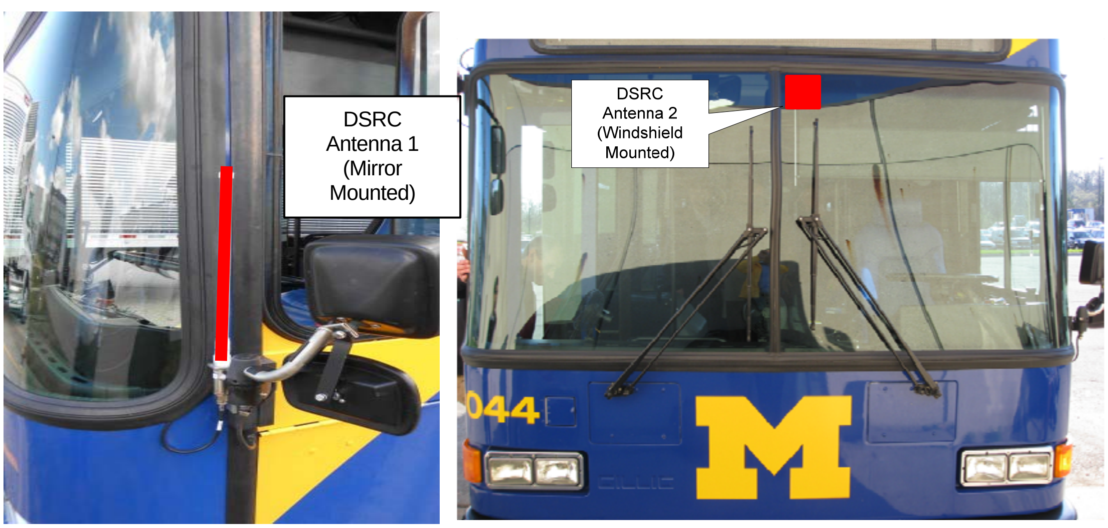
The following pictures (Figure 5-16) show an exterior picture of the intended hole location, an exterior view of the completed installation, and an interior view of the completed installation.

Source: Battelle

Figure 5-16. GPS Location Pre-Install (left), Exterior Post-Install (middle), Interior Post-Install (right)

DSRC Antennas

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). A visualization of the installation for the DSRC Antenna 1 and the DSRC Antenna 2 is shown in Figure 5-17.



Source: Battelle

Figure 5-17. DSRC Antenna 1 (left), DSRC Antenna 2 (right)

DC/DC Converter

The DC/DC Converter component of the TRP accepts a wide range DC voltage input that is typical with vehicle power. The nominal vehicle power input voltage has been designed for 12VDC. The TRP utilizes DC to DC Converter modules to converter vehicle power into regulated DC voltages that are used to power the TRP equipment. Two modules have been identified – a 12VDC to 12VDC conversion and 12VDC to 5VDC conversion (for the tablet power).

TRP Supporting Equipment

Additional TRP supporting equipment is installed on the transit vehicle – DAS and IMU.

Data Acquisition System (DAS)

The DAS is provided by Battelle subcontractor, University of Michigan Transportation Research Institute (UMTRI). The DAS is an UMTRI GEN5 DAS.

Hardware

The DAS is capable of recording a variety of vehicle dynamic information at variable sampling rates and/or based on various threshold settings or trigger events. The DAS also includes an integrated video monitoring system capable of recording driver actions, as well as events outside the vehicle.

The UMTRI DAS is highly reconfigurable. The system allows up to 8 separate image streams to be recorded simultaneously, with frame size, frame rate, and compression parameters tunable to each image. Video imagery is collected by defining continuous data collection and/or triggered video collection using circular buffering, such that the triggered video (or other data) can be captured at higher rates, if desired.

The DAS is, at minimum, capable of recording up to 10 days of operational data before requiring a download. The cellular modem feature allows for near real-time remote monitoring of system health. Data from the DAS can be downloaded directly to a laptop. The downloaded data is used for post processing analysis.

Software

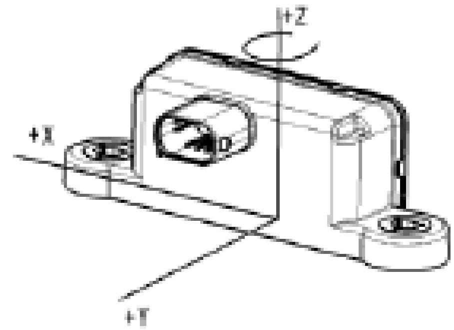
The GEN5 DAS application software runs on an UMTRI-configured version of Windows[1] XP Embedded OS. The DAS can run multiple application configurations depending how the “Mode” connector is jumpered or controlled via an external switch. Automatic, Demo, Maintenance, graphical user interface (GUI), Upload, and No CPU are common modes used in testing. In “Automatic”, the DAS powers up when the ignition switch is turned on, data is collected until ignition is turned off and then the DAS powers down. In “GUI” mode, an experimenter/operator can start and stop data collection, observe a real-time display, and enter test parameters and other metadata. “Upload” triggers an automatic file transfer to a server. “No CPU” prevents the computer and peripherals from being powered and is used when a vehicle is being serviced or when no data are to be collected.

Data signal definitions are entered into a metadata database, using a graphical user interface. This database is onboard the vehicle and is also available for analysis tools, enabling configurable and robust adaptation to different experiments.

[1] Windows is a registered trademark of Microsoft Corporation in the United States and other countries.

Inertial Measurement Unit (IMU)

The Inertial Measurement Unit (IMU) is a sensor that provides yaw rate, longitudinal and lateral acceleration that are used as inputs for DAS storage. The unit being installed is manufactured by Continental. The interface to the IMU is a CAN bus interface. For the TRP, a Local CAN Bus is being installed to provide data to the DAS. See the subsequent description of the Local CAN Bus within this document for further information regarding the Local CAN Bus. An outline drawing of the IMU is shown in Figure 5-18.



Source: Continental Automotive

Figure 5-18. IMU Outline Drawing

The IMU is mounted on the underside of the body of the transit vehicle with the flange down and the connector to the passenger side of the vehicle. The IMU is physically attached to a cross member that supports the bus frame and is located just behind the front wheel wells.

The pinout for the IMU is described in Table 5-8.

Table 5-8. IMU Pinout

Pin	Signal
1	Gnd
2	CAN_LO
3	CAN_HI
4	VCC (8VDC-16VDC, <200mA)

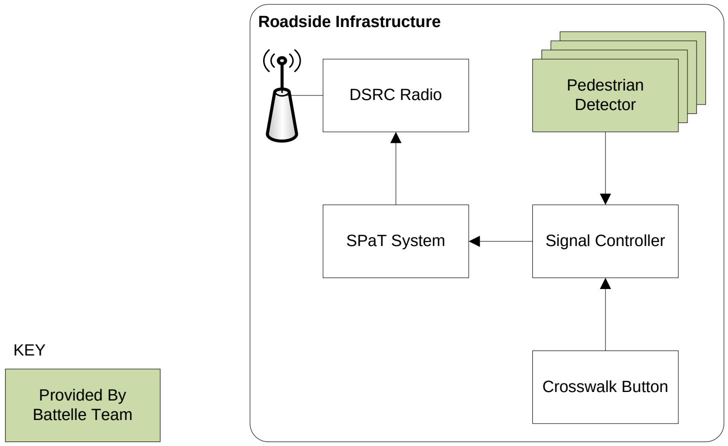
Source: Battelle

External Equipment

This section describes external equipment that was affected as a result of deploying the TRP or new installation of equipment to support the TRP.

Roadside Infrastructure – Intersection

The Roadside Infrastructure for an intersection is a set of equipment that is installed at a signalized intersection. Components of the Roadside Infrastructure – Intersection that are affected in support of the TRP program include Pedestrian Detectors, Signal Controller, SPAT System, Crosswalk Button, and DSRC Radio. A simplified block diagram of the Roadside Infrastructure components for an intersection is shown in Figure 5-19.



Source: Battelle

Figure 5-19. Roadside Infrastructure – Intersection Block Diagram

Pedestrian Detectors

Pedestrian detectors are new equipment that is installed at a signalized intersection. The Pedestrian Detectors are provided by Battelle. The Pedestrian Detector is a MS SEDCO SmartWalk™ XP. This unit is COTS and was installed by the Safety Pilot Test Conductor. There were four (4) units installed for the test intersection (two per crosswalk). The interface to each Pedestrian Detector unit is a discrete output indicating whether a pedestrian is detected. The SmartWalk™ XP is a microwave motion sensor that detects crosswalk occupancy. Each detector provides input to the Signal Controller.

Signal Controller

The Signal Controller is provided by the City of Ann Arbor. The Signal Controller was modified using Battelle provided and Econolite developed firmware to interface with the Pedestrian Detectors such that the Signal Controller knows when a pedestrian is detected. Pedestrian detection indication and Crosswalk Button status is provided to the SPAT Interface Device.

SPAT Interface Device

The SPAT Interface Device is provided by the Safety Pilot Test Conductor. The SPAT Interface Device was updated using Battelle provided firmware to accept pedestrian detection indication and crosswalk button status from the Signal Controller.

Crosswalk Button

The Crosswalk Button is provided by the City of Ann Arbor. The Crosswalk button allows pedestrians to signal the Signal Controller the desire to cross the street.

DSRC Radio at Signalized Intersection

The DSRC Radio located at the signalized intersection is provided by the City of Ann Arbor. The RSU transmits and receives messages in accordance to IEEE 802.11p and 1609.2 standards and the J2735 message standards.

Roadside Infrastructure – Curve

The Roadside Infrastructure for curves is a set of equipment that is installed at an equipped curve that broadcasts information pertinent to the curve. The RSU transmits and receives messages in accordance to IEEE 802.11p and 1609.2 standards and the J2735 message standards.

Remote Vehicle

Remote Vehicles are provided by the Safety Pilot Test Conductor. Remote vehicles are used in the Safety Pilot Model Deployment as vehicles that are equipped with DSRC Radios that interact with the TRP equipped transit vehicle. The DSRC Radio is used to transmit and receive messages in accordance to IEEE 802.11p and 1609.2 standards and the J2735 message standards. These remote vehicles are used to stimulate the Vehicle Turning Right Warning Application and the Basic Safety Applications.

External Interfaces

This section describes the various external interfaces to the TRP that are used or are being updated to support TRP. These interfaces are included for sake of completeness.

Pedestrian Detector – Signal Controller Interface

Each Pedestrian Detector provides an output relay contact closure either Normally Open or Normally Closed to indicate whether a pedestrian is detected. The output polarity is configurable. The manufacturer's specification for the Pedestrian Detector is shown in Table 5-9. For specific information on configuring the SmartWalk™ XP, refer to the SmartWalk™ XP Installation Manual.

Table 5-9. Specifications of the SmartWalk™ XP Sensor

Model Number	SmartWalk™ XP
Operating Frequency	24.125 gHz (K-band)
Detection Method	Microprocessor analyzed Doppler microwave detection
Pattern	Adjustable with cover off
Detection Angle	Adjustable
Detection Mode	Selectable: approach-only, depart-only or bidirectional motion
Detection Verification Time	0.1 to 5 seconds
Power Requirements	12 to 24 V AC or DC ± 10%
Power Consumption	1W maximum
Relay Output	Form C, rated at 1 Amp @ 24V DC (N.O. and N.C.)
Output Power	5mW typical, 2mW minimum
Relay Contact Ratings	0.5A:50V AC—1A:24V DC
Operating Temperature	-22°F to 158°F (-30°C to 70°C)
Physical Dimensions	4"W x 4"H x 7"L
Enclosure	Powder coated aluminum
Weight	4 lbs.

Source: MS SEDCO

The Signal Controller accepts the signal from the Pedestrian Detector and passes the information on to the SPAT Interface Device.

SPAT System – DSRC Radio Interface

The SPAT System consolidates information received from the Signal Controller which contains information for the Pedestrian Detectors and the Crosswalk phases and sends this information to the DSRC Radio for transmission. Two SPAT message Objects are of interest to the TRP program as indicated in Table 5-10.

Table 5-10. SPAT Message Objects

Object Identifier	Object Type
0x06	Current State
0x0B	Pedestrian Detected

Source: Battelle

The Current State object defines the current state of a particular known movement. The content of this object is determined by the type of lane(s) that it applies to; vehicle, pedestrian, or special lane. Table 5-11 provides the object format.

Table 5-11. Current State (0x06) Object Format

Field	Note
Object Identifier	0x06
Size	Number of bytes in the payload
Current State	Varies in length

Source: Battelle

For pedestrian lanes, this object defines the current signal state of the crosswalk indicators for a particular known pedestrian movement. This data object is only used for pedestrian lanes.

The enumerated values of this data object are as follows.

```
0 Unavailable or not equipped
1 Do not walk
2 Flashing, do not walk
3 Walk
```

The pedestrian detected data object indicates the possible presence of one or more pedestrians or other objects in the movements walk area. This data object is optional. Table 5-12 provides the object format.

Table 5-12. Pedestrian Detect (0x0B) Object Format

Field	Note
Object Identifier	0x0B
Size	0x01
Detect Flag	Unsigned 8-bit Integer

Source: Battelle

DSRC Radio Interface

The DSRC Radio transmits and receives messages in accordance to IEEE 802.11p and 1609.2 standards and the J2735 message standards. The TRP supports the following messages shown in Table 5-13 and Table 5-14.

Table 5-13. DSRC Received Messages

Common Message Name	PSID	Application	SAE J2735 Message	DSRC Channel	DSRCmsgID
Basic Safety Message (BSM)	0x20	EEBL, FCW, CSW, VTRW	MSG_BasicSafetyMessage	172	
Traveler Information Message (TIM)	0x8003	CSW	MSG_TravelerInformationMessage	Service Channel	
Signal Phase and Timing (SPAT)	0xBFE0	PCW	MSG_SignalPhaseAndTiming	172	0x8D
MAP message (aka GID)	0xBFF0	PCW	MSG_MapData	172	0x87
Security Credential Management	0x23	EEBL, FCW, CSW, VTRW, PCW	None	Service Channel	

Source: Battelle

Table 5-14. DSRC Transmitted Messages

Common Message Name	PSID	Application	SAE J2735 Message	DSRC Channel
Basic Safety Message (BSM)	0x20	TRP	MSG_BasicSafetyMessage	172

Source: Battelle

The BSM is transmitted approximately every 100 milliseconds.

Vehicle CAN Bus

The Vehicle CAN Bus is based on the SAE J1939 specification. The specific format and payload definitions of the messages are J1939 compliant. The TRP interfaces to the existing transit vehicle's Vehicle CAN Bus to decode the information listed in Table 5-15.

Table 5-15. Vehicle CAN Bus Information

Inputs	J1939 Label ID
Transit Vehicle's speed	0xFEF1 or 0xFEBF
Transit Vehicle's gear position (PRNDL)	0xF005
Transit Vehicle's brake status	0xFEF1

Source: Battelle

Local CAN Bus

The Local CAN Bus is based on the ISO 15765 specification. The specific format and payload definitions of the messages are ISO 15765-4 compliant. A new Local CAN Bus was installed to support providing IMU information to the DAS. The information being decoded and used is shown in Table 5-16.

Table 5-16. Local CAN Bus Information

Inputs	Label ID
Transit Vehicle's longitudinal acceleration	0x151
Transit Vehicle's yaw rate	0x150

Source: Battelle

GPS Interface

The GPS Interface follows the Interface Specification IS-GPS-200 standard. The GPS Receiver is embedded within the WSU. The COTS software provided within the WSU provides the mechanism for decoding the GPS position information through an API to user applications (i.e., TRP Safety Applications and Basic Safety Applications).

APPENDIX A. Terms, Definitions, and Acronyms

Abbreviation / Acronym	Definition
ASD	Aftermarket Safety Device
BSM	Basic Safety Messages
CONOPS	Concept of Operations
COTS	Commercial-Off-The-Shelf
CPU	Central Processing Unit
CSW	Curve Speed Warning
DAS	Data Acquisition System
DSRC	Dedicated Short-Range Communication
DVI	Driver Vehicle Interface
EEBL	Emergency Electronic Brake Light
FCW	Forward Collision Warning
GID	Geometric Intersection Description
GPS	Global Positioning System
GUI	Graphical User Interface
HV	Host Vehicle
OS	Operating System
PCW	Pedestrian at Crosswalk Warning
RSU	Roadside Unit
RTV	Room Temperature Vulcanizing silicone
RV	Remote Vehicle
SPAT	Signal Phase and Timing
TBD	To Be Determined
TRP	Transit Safety Retrofit Package
UMTRI	University of Michigan Transportation Research Institute
VTRW	Vehicle Turning Right Warning
WSU	Wireless Safety Unit

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