Vehicle-to-Infrastructure Rail Crossing Violation Warning

Architecture and Design Specifications

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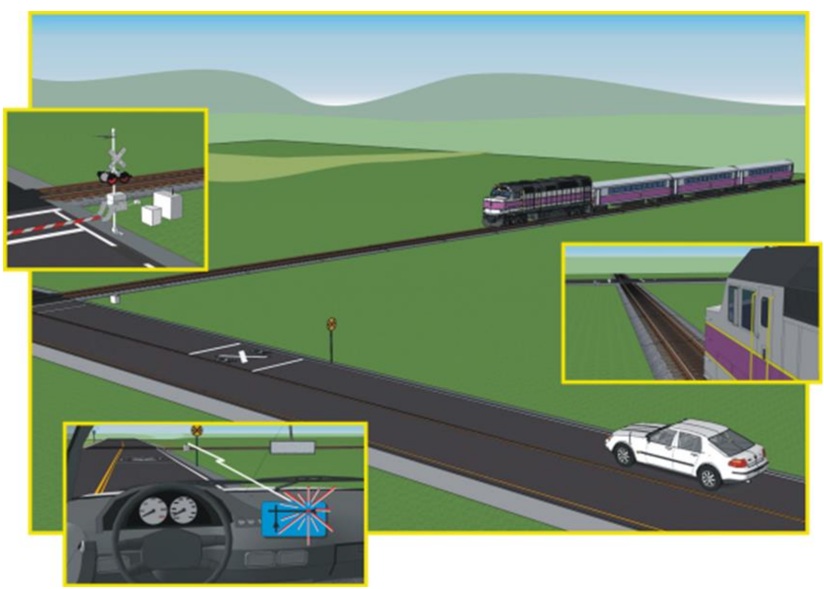

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Notice

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Revision History

Revision	Date	Change Description	Affected Sections/Pages
A	04/15/16	Initial Release	
Final	05/06/16	Changes throughout document based on comments received from US DOT.	All
Final Rev.2	06/06/2016	Changes throughout document based on comments received from US DOT.	All
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Final Rev. 4	08/10/2016	Changes throughout document based on comments received from FHWA and US DOT.	All

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Chapter 1 Scope

This Architecture and Design Specification for the Vehicle-to-Infrastructure Rail Crossing Violation Warning (RCVW) provides specifications that fulfill the following technical objectives as stated in Contract No. DTFH6112D00040-5016:

- Develop/integrate hardware interface and communication scheme for connecting a Roadside Unit (RSUv4) to existing active (Highway-Rail Intersection) HRI train detection system for the purpose of communicating HRI status to approaching connected vehicles.
- Develop vehicle retrofit device-based safety application to warn driver on a trajectory to violate active grade crossing safety.
- Test and evaluate performance of developed system/application under controlled lab and field conditions.

This document describes the structure and design of all the system components for the application and data flows including methods of installation. Required connected vehicle messaging and interfaces for communications between the Roadside-based Subsystem (RBS) and Vehicle-based Subsystem (VBS), and between the RBS and the existing rail grade crossing safety system leveraging the HRI signal preemption connection, are also included. This document, together with the Vehicle-to-Infrastructure Rail Crossing Violation Warning Concept of Operations and System Requirements Specification documents, provides design details suitable for the procurement of proof of concept material quantities.

Chapter 2 Applicable Documents

American Railway Engineering and Maintenance-of-Way Association (AREMA)

Communications & Signal Manual, Volume 1, Section 3 – Highway-Rail Crossing Warning Systems

US Department of Transportation

"Core System of Concept of Operations (ConOps)", US Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office

DOT HS 812 068 "Human Factors for Connected Vehicles: Effective Warning Interface Research Findings"

Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways, 2009 Edition Including Revision 1 and Revision 2 dated May 2012, US Department of Transportation Federal Highway Administration

DSRC Roadside Unit (RSU) Specifications Document Version 4.0 April 15, 2014

Vehicle-to-Infrastructure Rail Crossing Violation Warning Concept of Operations

Vehicle-to-Infrastructure Rail Crossing Violation Warning System Requirements Specification

Integrated Vehicle-to-Infrastructure Prototype (IVP) Design, May 20, 2016

Integrated Vehicle-to-Infrastructure Prototype (IVP) Interface Control Document (ICD), May 20, 2016

Institute of Electrical and Electronic Engineers (IEEE)

IEEE 1609	Standards for Wireless Access in the Vehicular Environment (WAVE)
IEEE 1609.0	2013 Standard for Wireless Access in Vehicular Environments
IEEE 1609.2	2013 – Trial Use Standard for Wireless Access in Vehicular Environments
IEEE 1609.3	2010/Cor-2012 – Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services
IEEE 1609.4	2010 – Trial Use Standard for Wireless Access in Vehicular Environments (WAVE) – Multi-Channel Operations
IEEE 1609.12	2012 Standard for Wireless Access in Vehicular Environments (WAVE) – Identifier Allocations

National Electrical Manufacturers Association (NEMA)

NEMA TS 2	2003 v.02.06 Standard for Traffic Controller Assemblies with NTCIP Requirements

NEMA 4.0 Nov 2008	NEMA-0183 Standard

The Radio Technical Commission for Maritime Services (RTCM)

RTCM 10403.2	Differential GNSS Services – Version 3

Society of Automotive Engineers (SAE)

SAE J2735	2015 Dedicated Short Range Communications Message Set Dictionary
SAE J2402_201001	Road Vehicles - Symbols for Controls, Indicators, and Tell-Tales 2010-01-07

Arada Systems

LocoMate User’s Guide v 1.26 April 18, 2013

Chapter 3 System Overview

System Overview and Context

The RCVW system will leverage the components and technologies developed under previous U.S. DOT connected vehicle deployment projects, and will include additional capabilities to enhance the safety of connected vehicles at highway rail grade crossings.

The RCVW system will consist of two physically separate subsystems: A Vehicle-based Subsystem (VBS) installed in connected vehicles and a Roadside-based Subsystem (RBS) integrated with roadside infrastructure at highway-railroad intersections (HRIs). Both subsystems will share some common hardware and software components, as well as include unique components. The RCVW system in its entirety will include the following components:

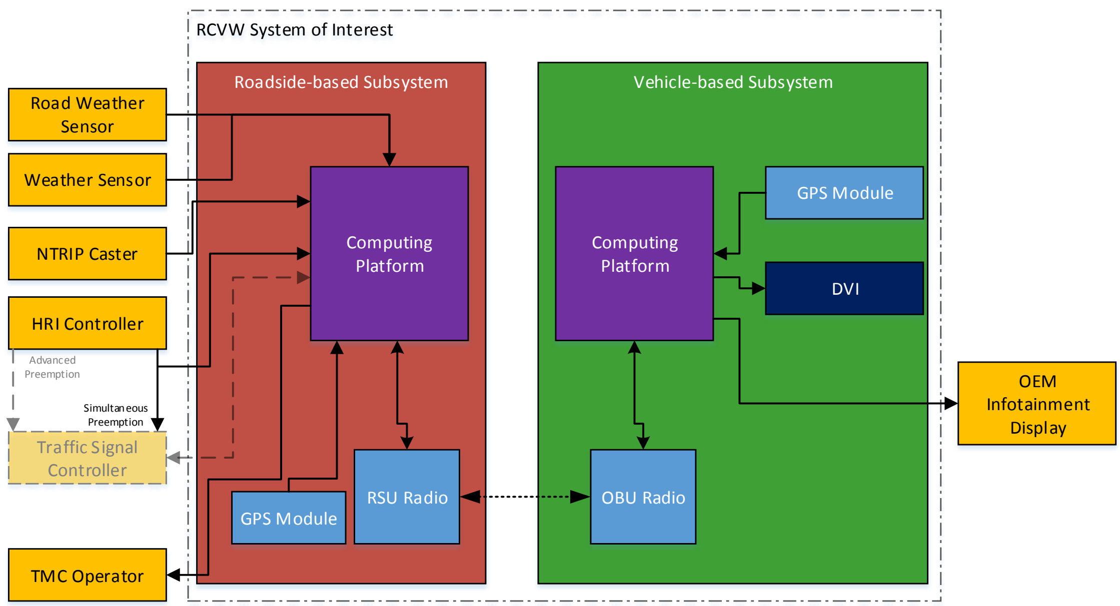
- Computing Platform (CP): The heart of the RCVW system are its computing platforms. CPs will control both RCVW subsystems. The RBS CP will reside within an Integrated V2I Prototype (IVP) module.
- Dedicated Short-Range Communication (DSRC) Radios – the VBS and RBS will utilize DSRC radios (an OBU and an RSU, respectively) as a low-latency wireless communication method to connect the two subsystems.
- Global Positioning System (GPS) – A GPS module will reside within the VBS and RBS to provide real-time lane-level position data to the VBS CP and RBS CP, respectively.
- Driver Visual Interface (DVI) – the RCVW interface to the connected vehicle driver will be developed to provide the vehicle driver RCVW warnings and alerts.

Information from sources external to the RCVW system will be accessed through their associated Transportation Message Exchange (TMX) plugins, and will include weather, road weather, and train detection signal status. The TMX software was developed for the Integrated Vehicle-to-Infrastructure Prototype (IVP) project to support infrastructure communications for CV applications. TMX is a singular communications platform with which a set of plugins are integrated in order to supply information to and receive information from deployed system components. The subset of TMX plugins created for the IVP project that are utilized for the RCVW project include: MAP, SPAT, DSRC Message Forward, GPS, and UTC plugins. Additional details on the IVP project and the plugins created can be found in the Integrated Vehicle-to-Infrastructure Prototype (IVP) Design and Integrated Vehicle-to-Infrastructure Prototype (IVP) Interface Control Document (ICD) documents. The V2I reference implementation project utilizes the design developed in the IVP project and provides platform specifications and documentation on how to deploy a system based in the location and needs of the deployed system. At this time, the V2I project has not produced documentation to reference. As a result, the RCVW system is therefore leveraging the IVP design and documentation.

A more descriptive overview of the RCVW System can be found in the "Vehicle-to-Infrastructure Rail Crossing Violation Warning Concept of Operations" document.

RCVW System Architecture Overview

A high level architectural view of the RCVW System is shown in Figure 3-1 below. Hardware components, their functionality, inputs, software, communications, and interface details are provided in the following sections of this document. Since the RCVW system is being developed on top of the existing TMX software and hardware that were completed on the IVP project, the design of the RCVW system is constrained to that of the system created by the IVP project. The TMX (IVP) plugin architecture can be found in the referenced Integrated Vehicle-to-Infrastructure Prototype (IVP) Design document and Integrated Vehicle-to-Infrastructure Prototype (IVP) Interface Control Document (ICD) document. For the following figures, the orange components are external entities to the RCVW system of interest. Entities with dashed lines and that are grayed out are external entities that may not be implemented in the demonstration of the RCVW system.



Source: Battelle

Figure 3-1. RCVW System Architecture Overview

Chapter 4 RCVW Computing Platform Architecture

Computing Platform

Identical CPs will be employed by the VBS and RBS. Both CPs will both employ the Transportation Message Exchange (TMX) software developed for connected vehicle applications under the IVP project. The TMX software allows plugins to share information between each other in an IVP system and broadcast information via a DSRC radio. Utilizing the TMX will facilitate a reduction in deployment time and effort through use of plugins developed under the IVP project. The VBS will also use the TMX as its main communication hub to receive DSRC messages from the RBS and make those messages available for other RCVW VBS plugins. The RCVW plugin on the VBS contains an application to use inputs supplied by other plugins, including J2735 MAP and SPAT, GPS, and weather information to determine when an RCVW warning or alert will be displayed.

Hardware

The hardware of the CP, which is being developed by Battelle, will consist of single board computer integrated with a DSRC radio. The CP will have multiple communication channels including Bluetooth, Wi-Fi, Cellular, Ethernet, DSRC, and USB. For the RCVW system, we will be utilizing the RS232, Ethernet, DSRC, and USB connections. The full specifications of the CP can be found in APPENDIX B.

DSRC Radio

The DSRC Radio transmits and receives messages in accordance to IEEE 802.11p and 1609.2 standards and the J2735 message standards. Communications to the RSU will be User Datagram Protocol (UDP) immediate forward-raw data payload messages as defined in the RSU 4.0 specification. A sample MAP message is shown below in Figure 4-1. Table 4-1 is a listing of the RCVW message types.

The RCVW system will utilize SPAT, MAP, and TIM messages from the J2735 message set. The MAP messages will contain the intersection geometry including the vehicle lanes and tracked vehicle lanes (train tracks) for the HRI. These messages will be used by the VBS to fix its location within the HRI (i.e., the HRI Hazard Zone or HRI Approach Zone). The SPAT message will contain the status of each lane in the HRI. For example, at a simple HRI with vehicle lanes crossing a train track and no traffic intersection present, when the HRI is not active, the status of the vehicle lanes will be 'permitted movement allowed' and the tracked vehicle lane will be 'stop and remain'. When the HRI is active, the status of the vehicle lanes will be 'stop and remain' and the tracked vehicle lane will be 'permitted movement allowed'. SPAT information will be used by the VBS to determine HRI status-based messaging. The TIM message will be used to transmit any errors from the RBS to the VBS when the RSU can still broadcast but the RBS has an error. For more detail on the format of these messages, see the 2015 SAE J2735 Dedicated Short Range Communications Message Set Dictionary.

```
Version=0.5
Type=MAP
PSID=0xBFF0
Priority=7
TxMode=CONT
TxChannel=172
TxInterval=0
DeliveryStart=
DeliveryStop=
Signature=True
Encryption=False
Payload=3081DE80011081090000000000000001000830101A481C63081C3800102A11BA119A01080
0418054A3B8104CE3585DF82020D068102004082010282020 7DB830306162184027D00850102A61
080041804FD888104CE35C39E82020CF68702016E880100A93C303A80020040A234A032A3300404
1C6BCDB304040420EC2B0404FAC8EC280404EF79F1210404EBC4FD660404E65310690404F9621
AA50404095B3F31AA3AA0383006A004800235293006A0048002010C3006A004800231383006A00
4800222113006A0048002010C3006A004800231483006A004800222118502100 1
```

Source: LocomateUsersGuide_v1.26.pdf section D2

Figure 4-1. Map Data File to be Sent over UDP

Table 4-1. RCVW System DSRC Message Types

Common Message Name	PSID	Application	SAE J2735 message	DSRC Channel	DSRCmsgID
Signal Phase and Timing (SPAT)	0x8003	RCVW	MSG_SignalPhaseAndTiming	172	0x8D
MAP message (aka GID)	0x8003	RCVW	MSG_MapData	172	0x87
TIM message	0x8000	RCVW	MSG_TravelerInformationMessage	178	0x30

Source: Battelle

GPS Receiver

UBlox NEO-7P, or similar, providing +/-2-meter accuracy.

Software

The Operating System (OS) selected for the CP is Linux as it allows a flexible platform for product development due to it being open source and easily customized.

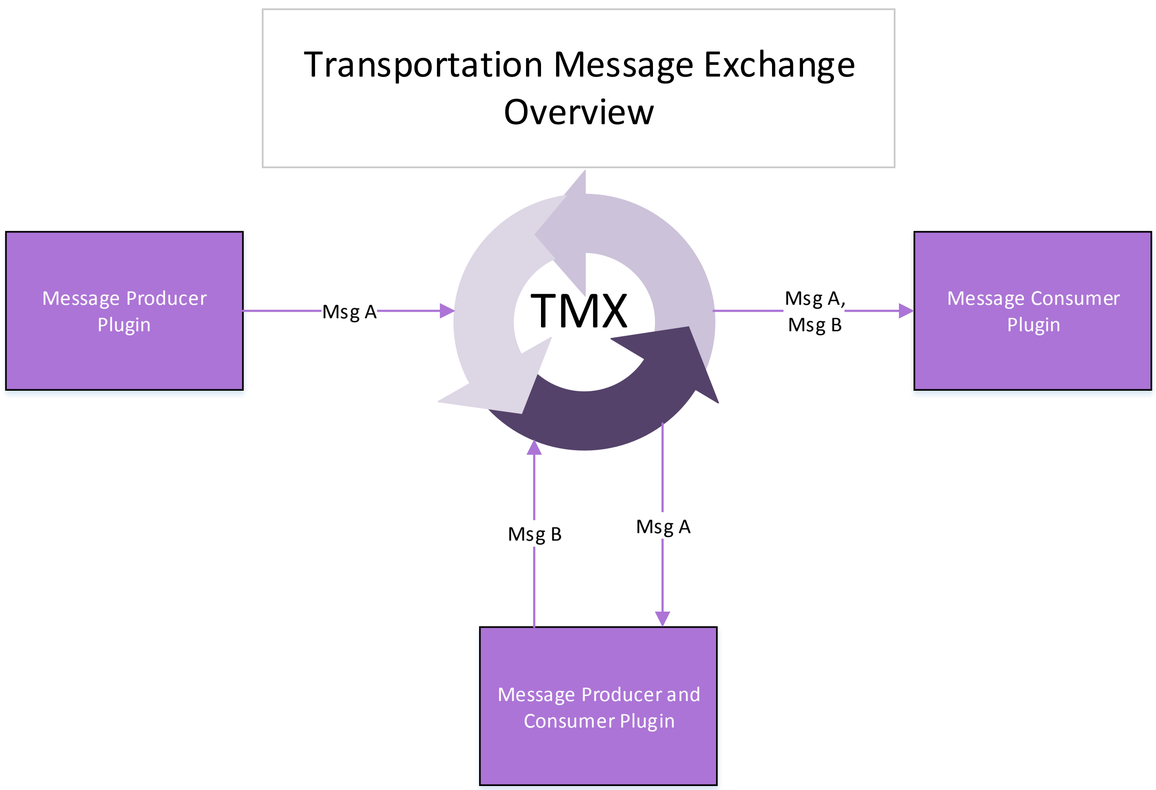
In addition to the OS layer, the RCVW design will include a common messaging framework for use across all connected vehicle projects. This common framework, TMX, is described in greater detail below.

Linux

The operating system running on the CPs will be the most recent version of the Linux Ubuntu distribution with Long Term Support (LTS). At this time, the most recent version is 14.04, which is built on the 3.14.28 Linux kernel. If the next version of Ubuntu with LTS is released as anticipated in April, 2016, it will be evaluated for inclusion suitability into the product baseline. The single board computer used in this product will also provide a Board Support Package (BSP) with appropriate kernel modifications to permit custom hardware.

Transportation Message Exchange (TMX)

A common software platform will be used in both RCVW subsystems. In both the VBS and RBS, the software developed will be designed to make use of the TMX platform. The TMX platform was developed by Battelle to support the IVP project, and subsequently refined for use in other projects. A high-level overview diagram of the TMX platform is presented below in Figure 4-2.



Source: Battelle

Figure 4-2. Transportation Message Exchange (TMX) Overview

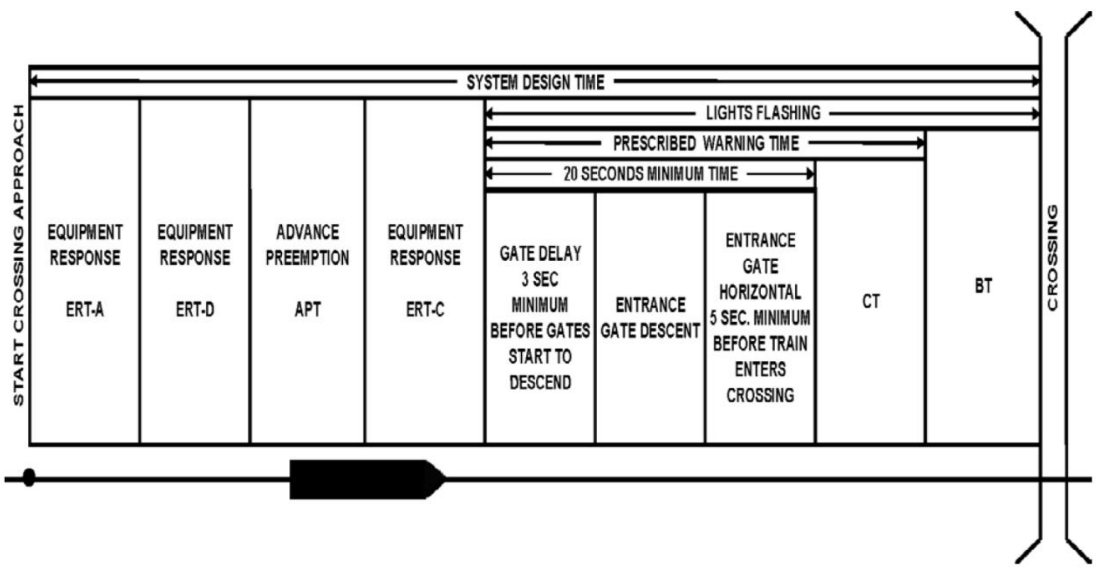
The system will be developed using the TMX platform integrated with a set of loosely coupled plugins that communicate through the TMX hub. Each plugin is responsible for registering with the TMX hub. As part of registration, a plugin will notify the hub as to which message types the plugin will produce and transmit to the TMX. Each plugin will additionally provide which message types it will request to receive from the TMX. Plugins can be either message producers, message consumers or both. One key advantage of using the TMX platform as a foundation for building the RCVW system is that plugins developed by other projects can be leveraged, reducing the time of development and testing.

Chapter 5 RCVW Design

RCVW Design Overview

The HRI Hazard Zone, the area between the stop bars on either side of the grade crossing, is site-specific and static. It will be determined by the RBS CP and communicated to the VBS CP for determining Rail Crossing Violation Warnings (RCVWs). The geospatial dimensions of the HRI Hazard Zone are a function of vehicle approach direction to the HRI, number of tracks, approach skew, and, where applicable, the type of active warning devices implemented at the HRI (e.g., two quadrant vs. four quadrant design). These same factors are used in determining the placement of warning gates and/or stop lines, as specified by the MUTCD and AREMA C&S Manual. The intention is that the HRI Hazard Zone and end of the HRI Approach Zone closely align with these rail warning markings and device placements. See Section 1.2 of the Vehicle-to-Infrastructure Rail Crossing Violation Warning System Requirements Specification document for more detail and definitions of the HRI Hazard Zone and HRI Approach Zone.

For HRIs equipped with active warning devices (i.e. flashing lights and gates as depicted in the right half of Figure 5-1 below) and interconnected with traffic signal controllers at nearby intersections, a preemption signal is issued when an HRI is active. CFR Title 49 Part 234 specifies that this signal must be issued at least 20 seconds before train arrival. However, factors such as the roadway speed limit, railway speeds, design of the active warning devices, HRI hazard zone size (inclusive of number of tracks), placement of the HRI warning devices, and additional site-specific factors are considered in determining if more than 20 seconds is required.

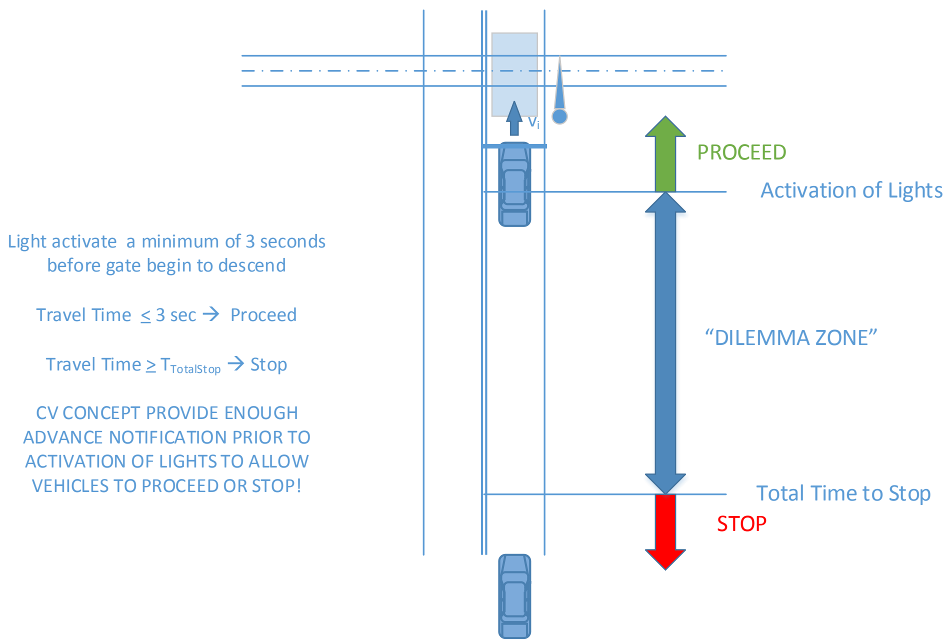


Source: AREMA Communications & Signal Manual

Figure 5-1 Warning Time Determination for Typical HRI with 2 Quadrant Gates

As illustrated in Figure 3-1 above, the RBS CP will rely on the HRI controller for receipt of the preemption signal. The RBS HRI Active message sequence will be triggered upon receipt of this preemption signal. While the RBS CP will receive simultaneous preemption signaling from the HRI controller, it will be designed to also accept advanced preemption signals through the TSC. Although advanced preemption signaling is rarely expected to be available and is most reliably received directly from the HRI controller, the capability to accept this signaling through the TSC may present an attractive option for certain installations.

When the RBS receives a preemption signal, it will broadcast an HRI Active message. If a VBS is within the HRI Approach Zone, it may issue alerts, and, if necessary, RCVWs[1]. It is critical that the VBS receives timely HRI Active messages and issues actionable RCVWs.



Source: Texas A&M Transportation Institute

Figure 5-2. "Dilemma Zone"

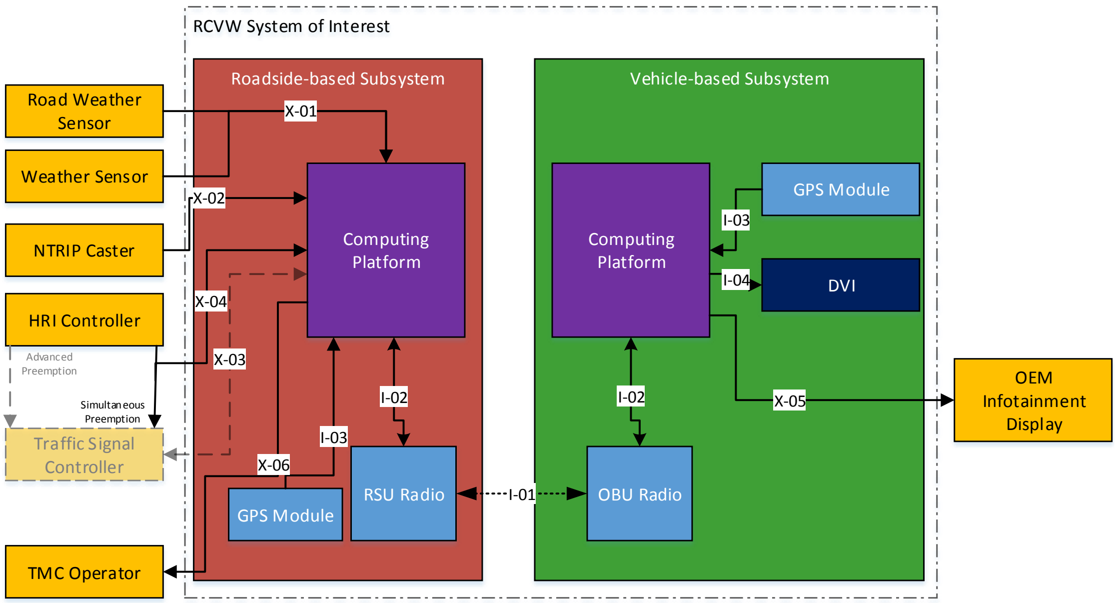
The VBS RCVW prediction algorithm will not change based on the availability of an advance preemption signal. The VBS RCVW algorithm will be conservative in that it will not calculate or issue alerts or warnings for vehicles to proceed within the HRI Approach Zone when the HRI is active, regardless of vehicle-condition factors. In other words, it will not encourage vehicle operators to delay taking action to stop within the HRI Approach Zone when an HRI is active or contribute to the perception they can or should proceed (i.e., it effectively ignores virtual or actual "Dilemma Zones"). The "Dilemma Zone" as depicted in Figure 5-2 above is the area within which vehicle operators may become confused as to whether they should attempt to stop or proceed.

[1]RCVW warnings within this zone will be determined by an algorithm executed by the VBS that will consider factors including typical reaction time of an operator; assumed worst case positional inaccuracy; vehicle speed, and braking performance; road parameters; and weather.

System of RCVW Interfaces

The functional analysis of the RCVW Architecture is depicted in in Figure 3-1. The functional decomposition of the RCVW is coincidently based on hardware boundaries.

The RCVW System will be composed of two subsystems, with interfaces as depicted below in Figure 5-3. The RBS will provide HRI attributes, road and weather conditions, and HRI status. The VBS determines and provides to the driver of the connected vehicle alerts, RCVWs, and clear HRI warnings.



Source: Battelle

Figure 5-3. RCVW System Overview with Interfaces

Table 5-1 below lists out each of the interfaces connecting the diagrammed subsystems, as well as the connections made to external systems.

Table 5-1. RCVW System Interfaces

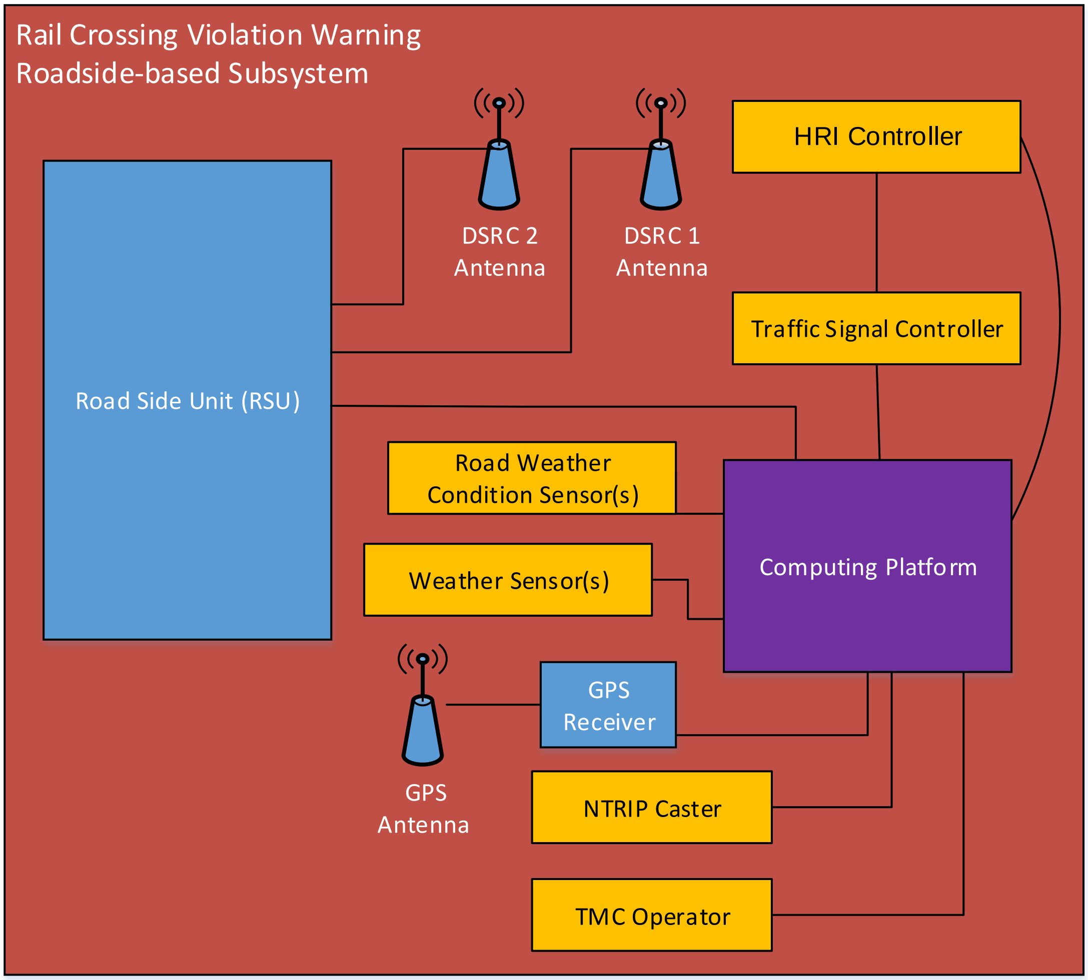
Interface Identifier	Interface Type	Exchanged information
I-01	DSRC	The RBS will send information to the VBS about the geographic layout of the HRI, local weather and road weather conditions, and HRI status. This information will be sent as MAP, TIM, and SPAT messages via DSRC.
I-02	TCP Socket	The RBS and VBS will have a socket connection to their DSRC radio to send and receive messages over DSRC.
I-03	TCP Socket	The RBS and VBS will have a socket connection to their GPS radio to receive position and time information
I-04	HDMI	The VBS will transmit warnings and alerts to DVI
X-01	NTCIP	The RBS will receive road weather and weather status information from weather and road weather sensors
X-02	TCP/IP	The RBS will receive NTRIP position correction information from an NTRIP caster network over a TCP/IP connection, and create RTCM messages that will be communicated via DSRC radio communications.
X-03	Signal Controller Status	The RBS IVP CP will receive the TSC status, which contains phase information needed to populate a SPAT message for the intersection. This information may also include the HRI preemption signal for potential use in future implementations not yet defined. **Note:** preemption signaling is, for RCVW purposes, received directly from the HRI controller.
X-04	Preemption Signal	The RBS IVP CP will receive the HRI preemption signal directly from the HRI controller
X-05	USB	The VBS will integrate with existing infotainment systems to display the alerts and warnings on an OEM display
X-06	Internet / Cellular	The RBS will send failure notifications to a TMC Operator.

Source: Battelle

Hardware Overview

Roadside-based Subsystem Hardware

A hardware block diagram for the RCVW RBS is shown in Figure 5-4. This figure identifies the main components and the associated interconnects that are required.



Source: Battelle

Figure 5-4. Roadside-based subsystem hardware block diagram.

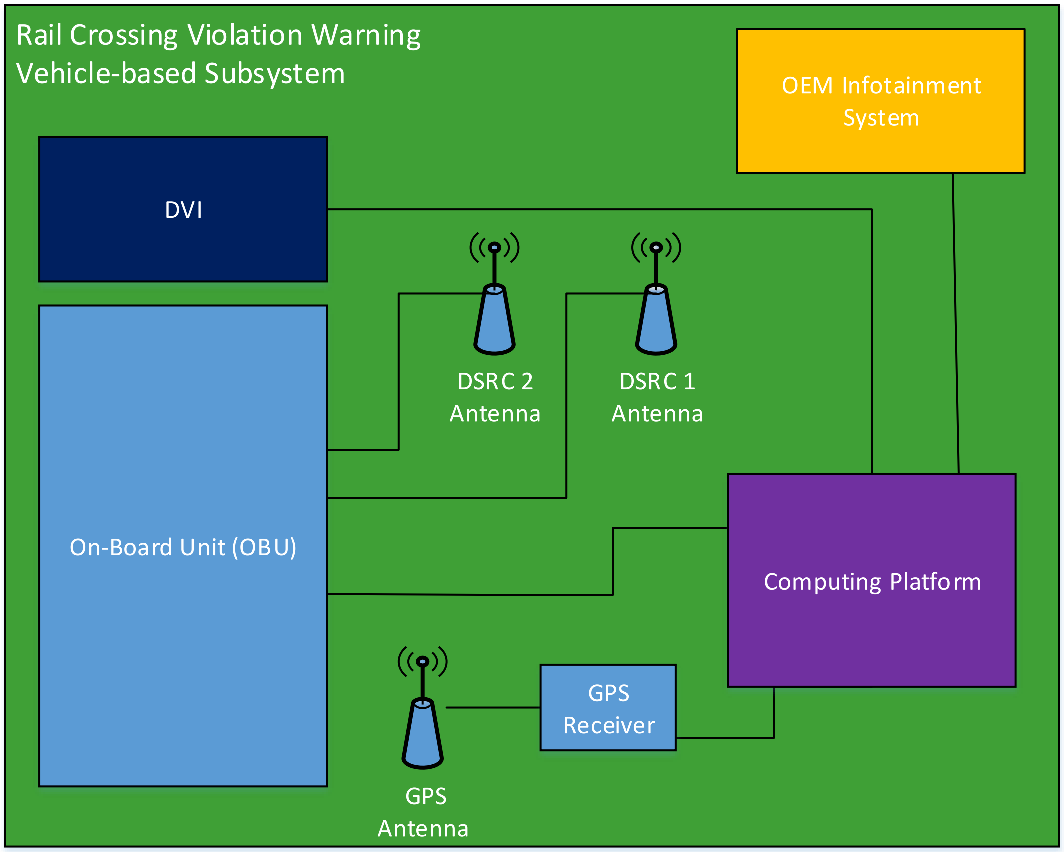
List of Hardware to be Provided Includes:

- RCVW /RBS
    - Computing Platform
    - DSRC Radio
    - DSRC Antenna 1 and DSRC Antenna 2
    - Road Weather Condition and Weather Sensors
    - GPS Receiver

A more in depth description of each hardware component is presented below.

Vehicle-based Subsystem Hardware

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



Source: Battelle

Figure 5-5. Vehicle-based subsystem hardware block diagram.

List of Hardware to Be Provided Includes:

- RCVW/ VBS
  - Computing Platform
  - DSRC Radio
  - DSRC Antenna 1 and DSRC Antenna 2
  - GPS Receiver and Antenna
  - DVI
- Supporting Equipment
  - OEM Infotainment System

A more in depth description of each hardware component is presented below.

Software Overview

The software for the RCVW system will be developed for each of the two RCVW Subsystems. Both the RBS and VBS will be built on a common hardware platform. Because of this common hardware, much of the software platform can also be the same for both subsystems.

At the heart of the RBS and VBS will be a CP. This CP will employ a Linux OS, which will provide access to the underlying hardware components. Both subsystems will also use a common software platform operating in tandem with the OS, which will permit rapid development of the RCVW features and applications and will leverage existing IVP project capabilities across the RCVW project. Additional details for the design of each software system is provided below.

RCVW Inputs and Outputs

There are five primary data input types to the RCVW system:

The first input type is HRI attributes, characteristics and geography that are transmitted in a SAE J2735 MAP message. The characteristics and attributes of the intersection include the lane types (pedestrian, vehicle, etc.), the permitted lane movements (straight, left turn, right turn, etc.), lane direction (approach or egress) and lane connection information all provide the best representation of the intersection to approaching vehicles. The MAP message contains all the HRI information necessary for a vehicle to place itself in the MAP. These messages will be transmitted from the RBS RSU to the VBS OBU via DSRC.

The second is HRI status. The status, either active or inactive, is provided to the RBS by the HRI controller. The HRI status will be transmitted by the RBS RSU via the SAE J2735 SPAT message. The SPAT information will be used by the VBS RCVW application for determining when a RCVW alert/warning should be issued.

The third is GPS position and time. Position fix information to determine the position of the VBS in the HRI MAP is a required input for the RCVW algorithm. The position accuracy of the GPS must be sufficient to allow placement of the VBS within the lane information provided by the J2735 MAP message. Vehicle speed will be used by the VBS HRI algorithm in addition to other parameters when determining if RCVW warnings and alerts should be displayed.

The fourth is the road weather condition information. These data are communicated to the VBS via the RBS and are used in the RCVW prediction algorithm.

The fifth is vehicle type information. This information will be provided via a configuration file into the VBS RCVW application for use in the RCVW prediction algorithm.

RCVW System

This section contains a detailed description of each subsystem along with the software and hardware that will be either developed or modified to support the determination of RCVWs for connected vehicles.

Vehicle-based Subsystem

The VBS is a collection of hardware and software for the purpose of alerting/warning the connected vehicle driver of imminent rail crossing violations.

Hardware

The hardware for the VBS will consist of a computing platform and a driver visual interface.

Computing Platform

The CP will serve as the central hub for all RCVW activity on the connected vehicle. This device will communicate with the other RCVW subsystems as well as the external equipment on the connected vehicle. More details on the CP are in Chapter 4.

Driver Visual Interface

The DVI for displaying and annunciating RCVWs will be a commercial-off-the-shelf (COTS) external LCD display with speakers. A high-resolution LCD display will display warnings and alerts to the driver. For example, an alert is displayed and annunciated if a “known” RBS is not operational. Similarly, a warning is displayed and annunciated if vehicle is on course to commit an RCVW and/or the roadway vehicle is stopped within the HRI hazard zone. The speakers will have adjustable volume allowing the driver to hear the aural annunciations inside a vehicle above ambient noise.

GPS

The GPS module will be used to determine the position of the VBS. The position accuracy of the GPS must be sufficient to allow placement of the VBS within the lane information provided by the J2735 MAP message. The requirements document specifies +/-2 meters as the of GPS accuracy to achieve lane-level accuracy for the VBS. We are planning to use the UBlox NEO-7P chip to obtain the needed level of GPS accuracy. The necessary differential corrections will be provided by the RBS.

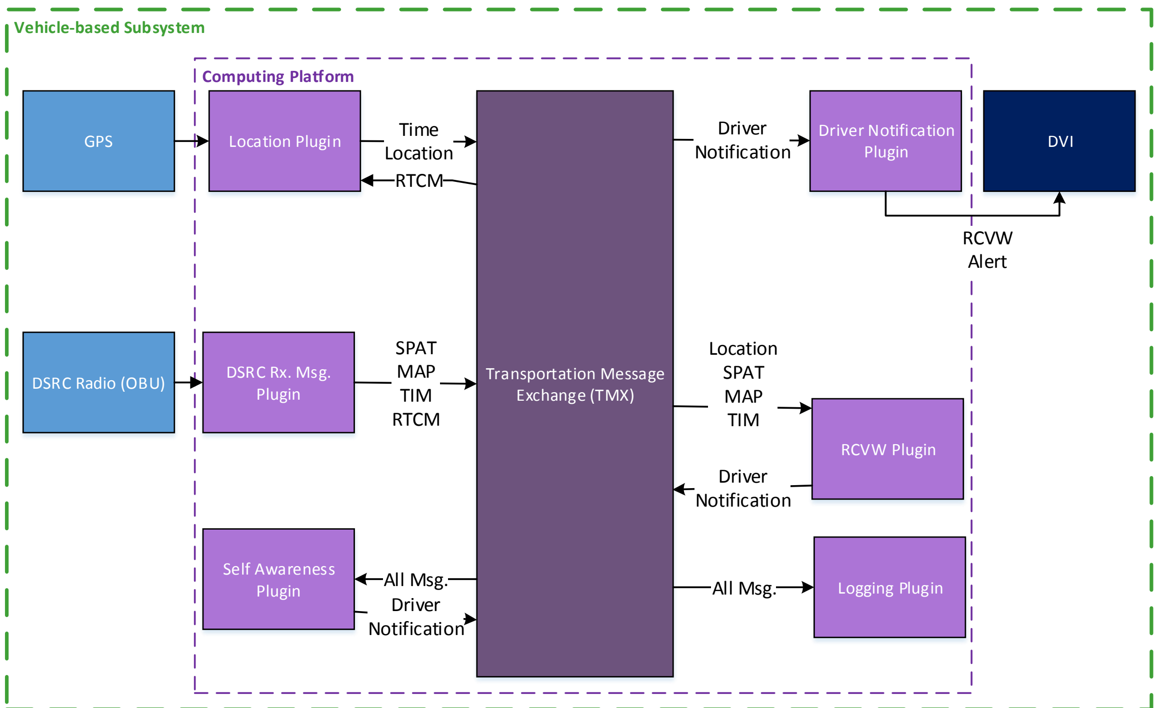
OEM Infotainment System

The OEM (Original Equipment Manufacturer) Infotainment System is an in-vehicle system produced by the vehicle manufacturer that controls various non-safety critical functions like the radio and climate control. Most new vehicles are equipped with such systems. Examples of infotainment systems are the Ford Sync system, Chrysler UConnect, Android Auto and Apple CarPlay. Interface to this system will be achieved by a USB connection from the CP to the Infotainment System.

Software

The software for the VBS will generate alerts, predicted RCVWs, and clear HRI warnings to the driver of a connected vehicle.

This RCVW application will be designed to interface with the TMX software platform. The logic required to perform the needed functions will be developed as a set of plugins. Each plugin will perform a single discrete function. The diagram in Figure 5-6, illustrates the plugins, including how they interact with RCVW system components.



Source: Battelle

Figure 5-6. Vehicle-based Subsystem Software Design

Table 5-2, below, provides a brief description of each plugin and its associated data exchange. The internal format of the messages is described in the Integrated Vehicle-to-Infrastructure Prototype Design document's IVP JSON Message Structure section.

Table 5-2. RCVW System VBS TMX Plugins

Plugin	Description	Plugin Input	Plugin Output
Location Plugin	This plugin will interact with the GPS hardware and provide the current location and time information to the rest of the system. The location plugin will also correct the GPS location information by using correction information from the J2735 RTCM message.	Output stream from GPS receiver RTCM message	Location Message
DSRC Receive Message Plugin	The DSRC Receive Message plugin is responsible for taking messages received via the DSRC radio and relaying those to the rest of the system.	Messages from DSRC Radio	SPAT Message MAP Message TIM Message RTCM Message
Driver Notification Plugin	The Driver Notification plugin will be responsible for alerting/warning the vehicle driver in an audible fashion through an external speaker and displaying visual alerts to the driver through the LCD, via visual and audible cues.	RCVW Warning Clear HRI RCVW System Failure	Suitable audio output annunciated via DVI speakers Events shown on driver display
Logging Plugin	The Local Logging plugin will monitor the state of the system and record the state information to the local system for later review.	All Messages	Data logged to local filesystem
RCVW Plugin	The RCVW Plugin uses an application to process information from VBS support plugins and the CP to determine if and when to issue driver warnings and alerts.	SPAT Message MAP Message TIM Message Location Message	Driver Notification Message
Self Awareness Plugin	The Self Awareness Plugin will monitor the VBS' location against a known set of RBS'. When the VBS detects that it is in a RBS zone, it will notify the driver if it doesn't receive a message from the RBS.	All Messages	Driver Notification

Source: Battelle

Figure 5-7 below shows the applications and their data flow inside the RCVW VBS system. To simplify the diagram, the TMX core message router is not shown. Plugins that produce and send messages to TMX will have a line to the consumer of those messages. Additional details regarding the RCVW application for the VBS are described below.

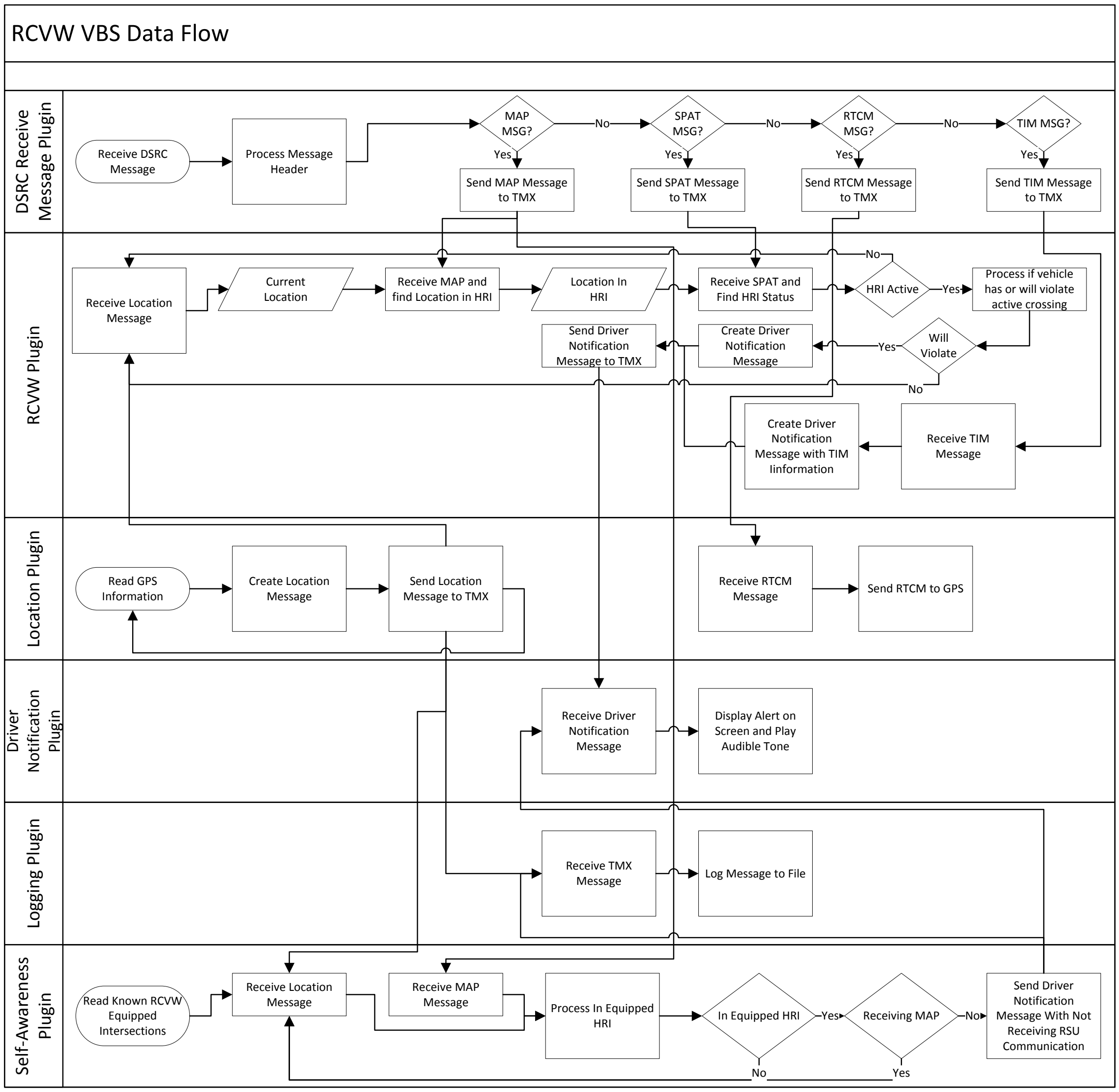


Figure 5-7 RCVW VBS Applications Data Flow

VBS Support Plugins

The RCVW application plugin is supported by a suite of plugins designed to interface with the TMX platform. The Location plugin will correct the GPS position using the correction data from the RTCM J2735 message. The DSRC Receive Message plugin acts as the interface to the DSRC Radio and converts the received J2735 messages into a common format used by the TMX platform. The Driver Notification Plugin is responsible for both issuing visual and audible warnings and alerts to the driver and uses notification outputs from the RCVW plugin application to do so.

Self Awareness Plugin

The VBS Self Awareness Plugin will notify the driver with an alert when the VBS is on track to intercept an HRI and is within nominal DSRC reception range of a “known” RBS-equipped HRI” and has not received any messages. The alert from the Self Awareness Plugin will notify the driver that the RBS is not operating properly, and to proceed with caution.

RCVW Application Plugin

The RCVW application plugin continuously executes the RCVW algorithm and actively monitors DSRC MAP messages received. Based on the receipt of the MAP message from the RBS and the current vehicle location provided by the Location plugin, the RCVW application plugin will determine if a vehicle is approaching an HRI, and more importantly, its location relative to the HRI. When it has been determined that a vehicle is approaching the HRI, the application plugin will receive the HRI Hazard Zone geospatial information, and compute the HRI Approach Zone for a vehicle based on typical operator response time, vehicle characteristics, and instantaneous location and speed. The distance derived by the HRI Approach Zone ensures that the driver will be provided a timely warning in the event of imminent predicted rail crossing violations. The RCVW application plugin will monitor the received SPAT messages for the HRI Active status. When a vehicle is within the HRI Approach Zone of an active HRI, the RCVW application plugin will determine if an alert/warning is needed to alert the vehicle operator of a potential RCVW.

Roadside-based Subsystem

The RBS is responsible for monitoring and reporting the status and condition of the HRI. The RBS will wirelessly transmit to approaching vehicles specific details regarding the physical layout of the intersection, weather-related road conditions, and HRI status.

Hardware

The RBS will consist of the following hardware:

- Computing Platform (CP) to include:
    - Interface(s) to receive HRI status
    - Bi-directional interface(s) with roadway traffic controller(s) (if present)
    - Interface(s) to receive weather and road weather sensor data
    - Interface to internet to receive RTCM correction information
    - GPS
- Weather sensors
- Road weather sensors

It will communicate with RCVW VBS-equipped connected vehicles as well as the external equipment associated with RCVW prediction at the HRI. The RBS CP will be an instance of the CP as described in Chapter 4.

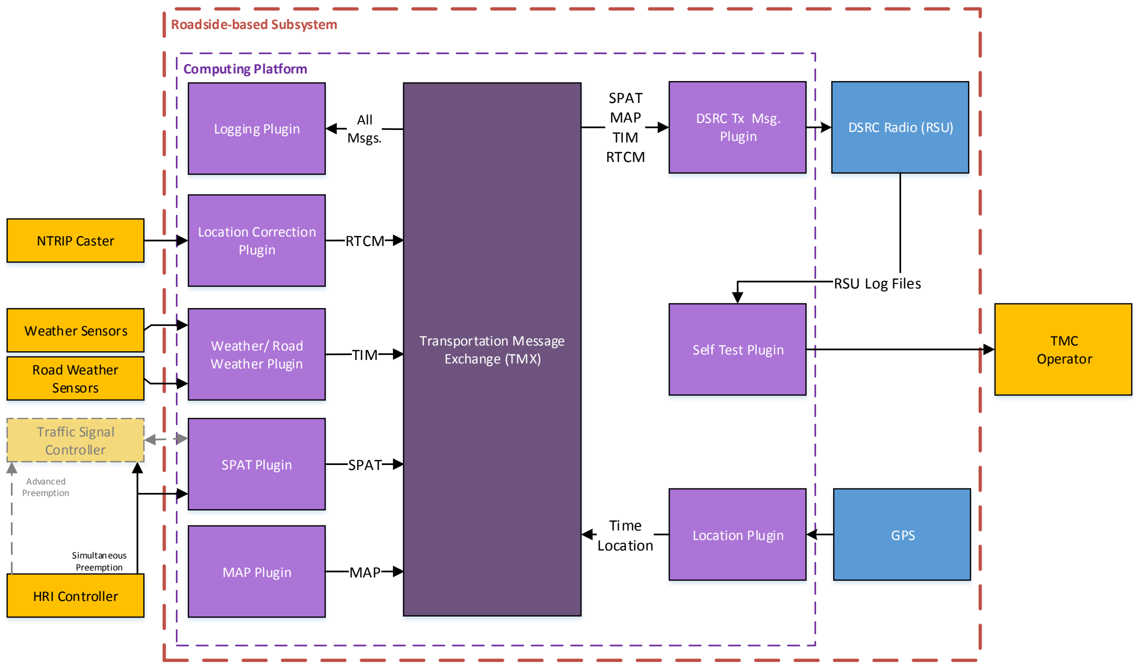
Train Detection Signal

The train detection system is the source of the HRI status within the RCVW SPAT message. The HRI Active message will be initiated exclusively by the preemption/train detection signal from the HRI controller.

Software

The RBS software is designed to provide supporting information to the RCVW plugin operating on the VBS. The RBS will provide detailed information about the intersection so that the VBS may determine if an RCVW will be presented to the driver. Key information exchanged will include a message providing detailed roadway geometry for the intersection, weather-related road conditions, and HRI status.

The RBS software will be designed to interface with the TMX software platform as a set of plugins. Each plugin will perform a single discrete function. Whenever practical, common functionality between the two subsystems will utilize the same plugins. The diagram below in Figure 5-8 provides a block diagram showing the design of the software.



Source: Battelle

Figure 5-8 Roadside-based Subsystem Software Design

The core plugins in the RBS provide situational information for the intersection. Both the MAP and SPAT plugins were developed for the IVP project and will be used to the maximum extent practical. Required modifications to the SPAT system include adding functionality to monitor the preemption signal status in order to set the lane status to stop and remain so when the HRI is active. The remaining plugins will support the primary task of providing the other required information. Table 5-3 below outlines each plugin to be used in the RBS along, with the messages produced and consumed by each plugin.

Table 5-3. RCVW System RBS TMX Plugins

Plugin	Description	Plugin Input	Plugin Output
MAP Plugin	The MAP plugin will be responsible for generating the appropriate MAP message for the specific intersection.	HRI geometry loaded from filesystem	MAP Message
SPAT Plugin	The SPAT plugin is responsible for interfacing with the HRI controller and generating SPAT messages containing the status of the HRI. The SPAT plugin is also responsible for interfacing to the TSC.	Output from HRI signal controller	SPAT Message
DSRC Transmit Message Plugin	The DSRC Transmit Message Plugin is responsible for taking internal messages flagged for transmission and ensuring they are sent out via the DSRC radio.	SPAT Message MAP Message TIM Message RTCM Message	Input to DSRC radio to send appropriate message
Weather / Road Weather Plugin	This plugin will interact with external weather and road weather sensor hardware and provide the current local weather related road conditions.	Output stream from RWIS sensors	TIM Message containing Weather Report
Location Plugin	This plugin will interact with a GPS receiver and supply the system with location and time information.	GPS NEMA Sentences	Time and Location Information
Location Correction Plugin	This plugin will interact with a state-wide NTRIP Caster network and receive correction information	Location Correction Information	RTCM Message
Logging Plugin	The Local Logging plugin will monitor the state of the system and record the state information to the local system for later review.	All Messages	Data logged to local filesystem
Self-Test Plugin	The Self-Test Plugin will monitor the RBS' log files for any failures, and notify a TMC Operator of those failures.	RBS Log Files	SMS or Email

Source: Battelle

MAP and SPAT Plugins

The MAP and SPAT plugins work in concert to provide the information needed by approaching vehicles to determine whether a warning or alert should be issued given the current situation. The MAP message provides the geographic context for which the SPAT Message information is applied. The content of a MAP message is used by the VBS CP to construct a detailed layout of each element of the roadway approach to the HRI. The RCVW application will analyze the MAP information to determine if the vehicle is within the HRI Approach Zone and where specifically the vehicle is located relative to the HRI. Each intersection used for testing and demonstration will have a unique MAP message prepared and configured so that the MAP plugin will broadcast its unique information. The data flow in the RCVW VBS system can be found in Figure 5-7. Figure 5-9 shows the flow of the MAP message in the RCVW RBS system.

If the HRI is not adjacent to a preempted highway intersection, the RBS will only produce SPAT messages containing the HRI active status information for the HRI. When the HRI is in proximity to a preempted highway intersection, the RBS may be configured to send two types of SPAT messages; one containing the HRI active for the HRI, and a second containing the signal phase and timing information for the highway intersection. The RBS will likewise be configured to send MAP messages containing HRI and highway intersection details. Even though the HRI also sends its preemption signal to the TSC of the highway intersection, the two systems will be treated independently by the RBS. The SPAT message for the HRI contains the HRI active signal state as “event status”. The SPAT message contains an intersection ID which will be used to correlate the SPAT message to its MAP message. The VBS uses both MAP and SPAT messages to determine “event status” (i.e. stop and remain, protected movement allowed, permissive movement allowed, protected clearance allowed, etc.) of a lane in the MAP message. For the RCVW project, we will be using the event status “stop and remain” as the trigger for HRI active. Figure 5-10 shows the flow of the SPAT message in the RCVW RBS system.

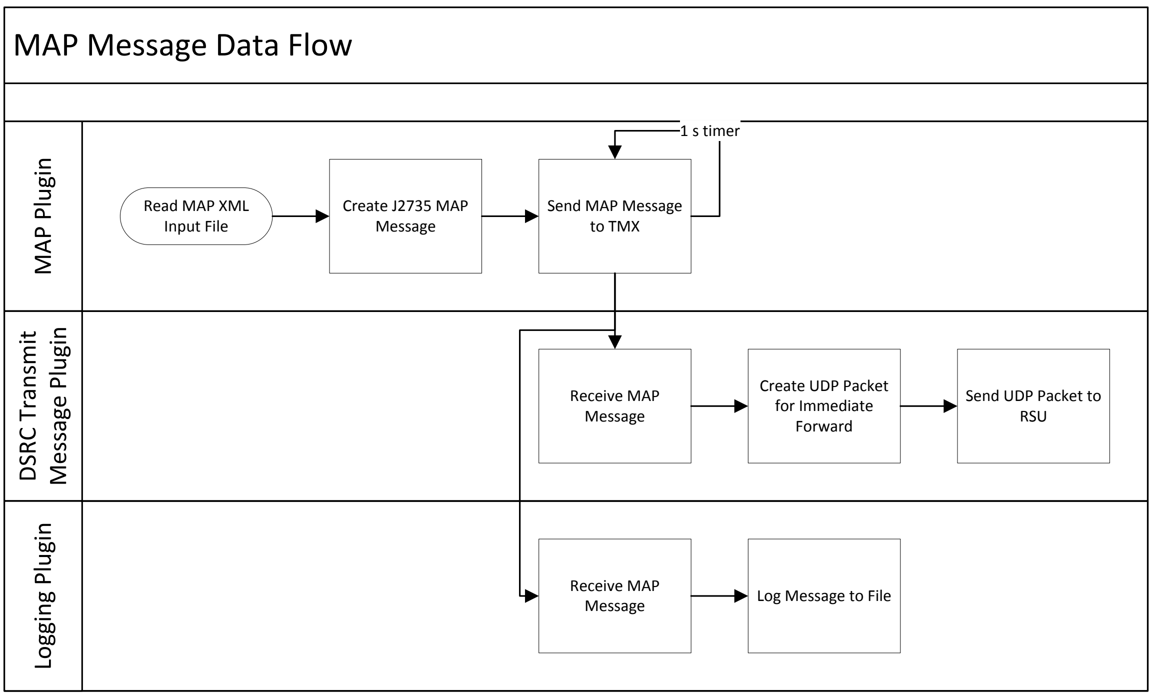


Figure 5-9 MAP Message Data Flow

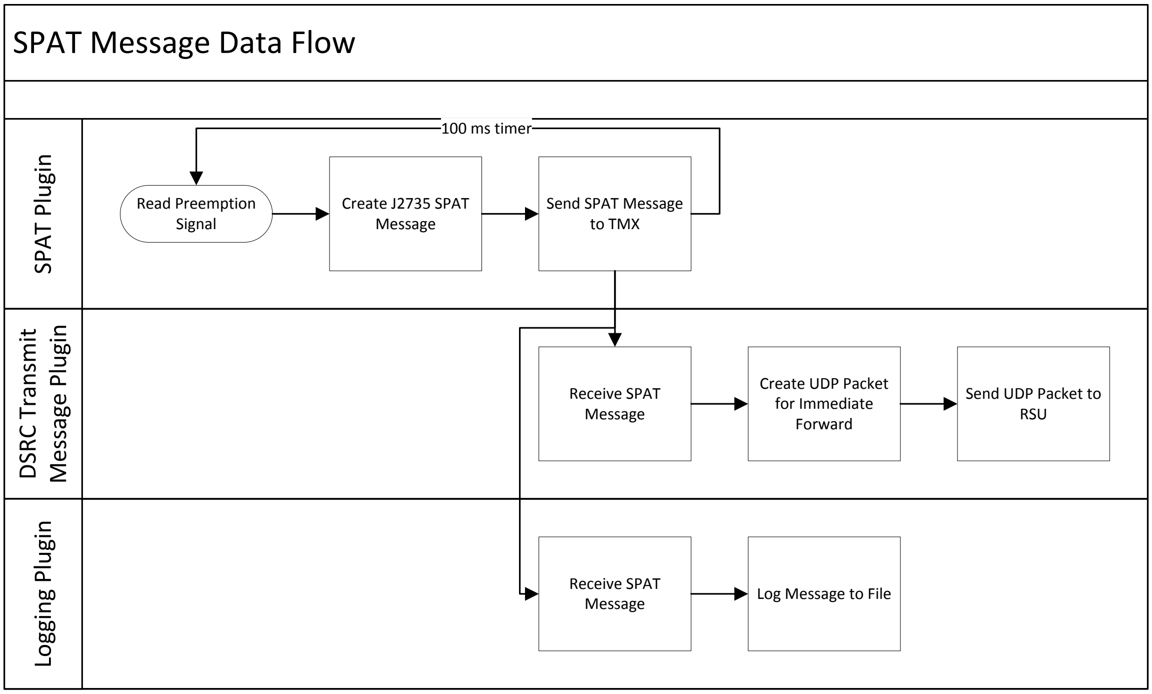


Figure 5-10 SPAT Message Data Flow

Weather / Road Weather Plugin

The Weather / Road Weather plugin will interface with weather and road weather sensors, either locally over an NTCIP connection or remotely via an internet connection depending on what devices are available at the intersection. This plugin will retrieve all weather information available and create a TIM message containing the weather report, which includes pavement condition, precipitation type, and precipitation rate. Weather/road report information is supplied by the RBS to the VBS for use in determining the timing of an RCVW warning or alert. The data flow of the TIM message produced by the Weather / Road Weather Plugin is found in Figure 5-11.

Self-Test Plugin

The Self-Test plugin will communicate with the RBS to get failure information from the RBS' log files. If a connection cannot be made to the RSU, a network failure notification will be sent to the TMC Operator. If the Self-Test plugin finds a failure logged in the RBS's log files, the Self-Test plugin will send a notification to the TMC Operator of that failure. The notifications can be sent via email or text via short message service (SMS) depending on the deployment infrastructure. Figure 5-11 shows the data flow of the TIM message produced by the Self-Test Plugin.

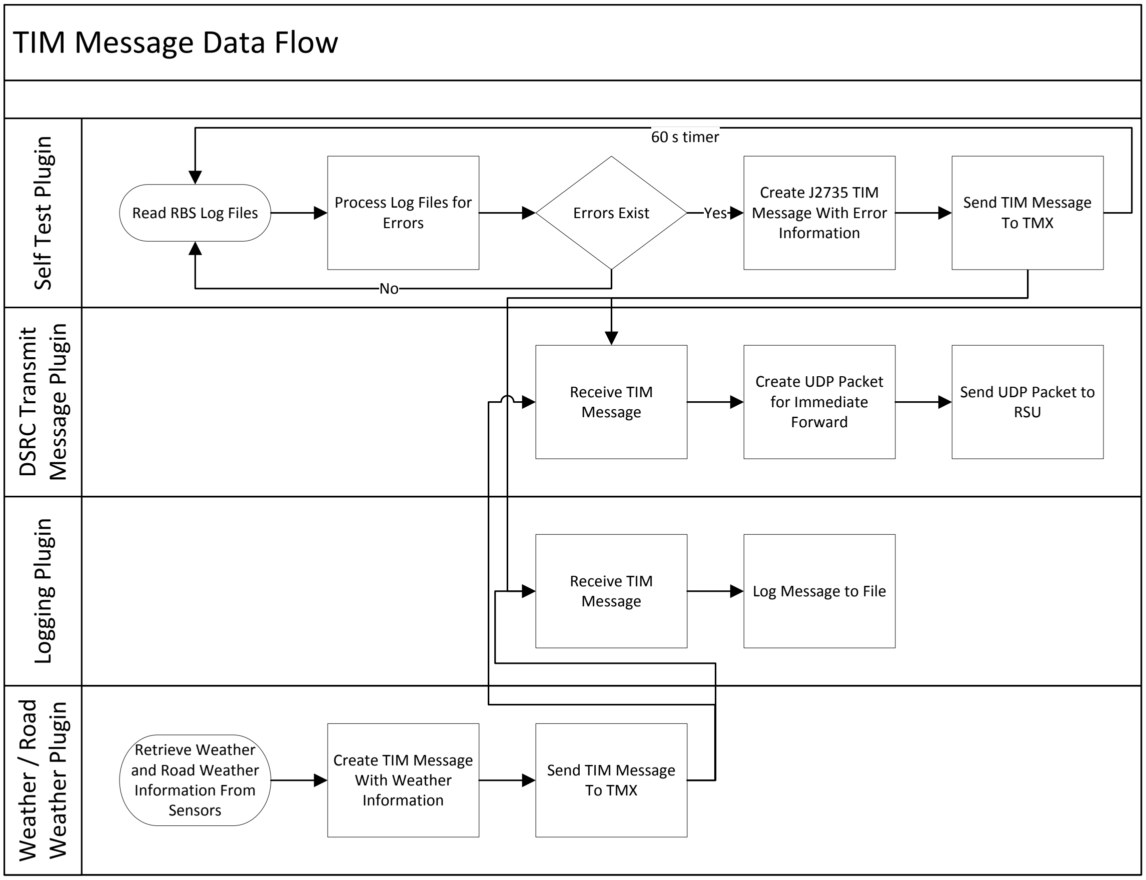


Figure 5-11 TIM Message Data Flow

Location and Location Correction Plugins

The Location plugin will receive NEMA-0183 GPGGA and NEMA-0182 GPVTG messages produced by the RBS' GPS module, and parse the information into location and time messages that can be used by the plugins in the RBS computing platform. The RCVW system will utilize the current Location Correction Plugin that was created for the IVP project. The Location Correction Plugin will communicate with a state-wide position correction information system, and receive periodic location correction information. The Location Correction Plugin will generate a J2735 RTCM message with the provided correction information, and send that message into the computing platform to be subsequently forwarded to the DSRC Radio by the DSRC Transmit Message Plugin. Figure 5-12 diagrams the data flow of the RTCM message produced by the Location Correction Plugin.

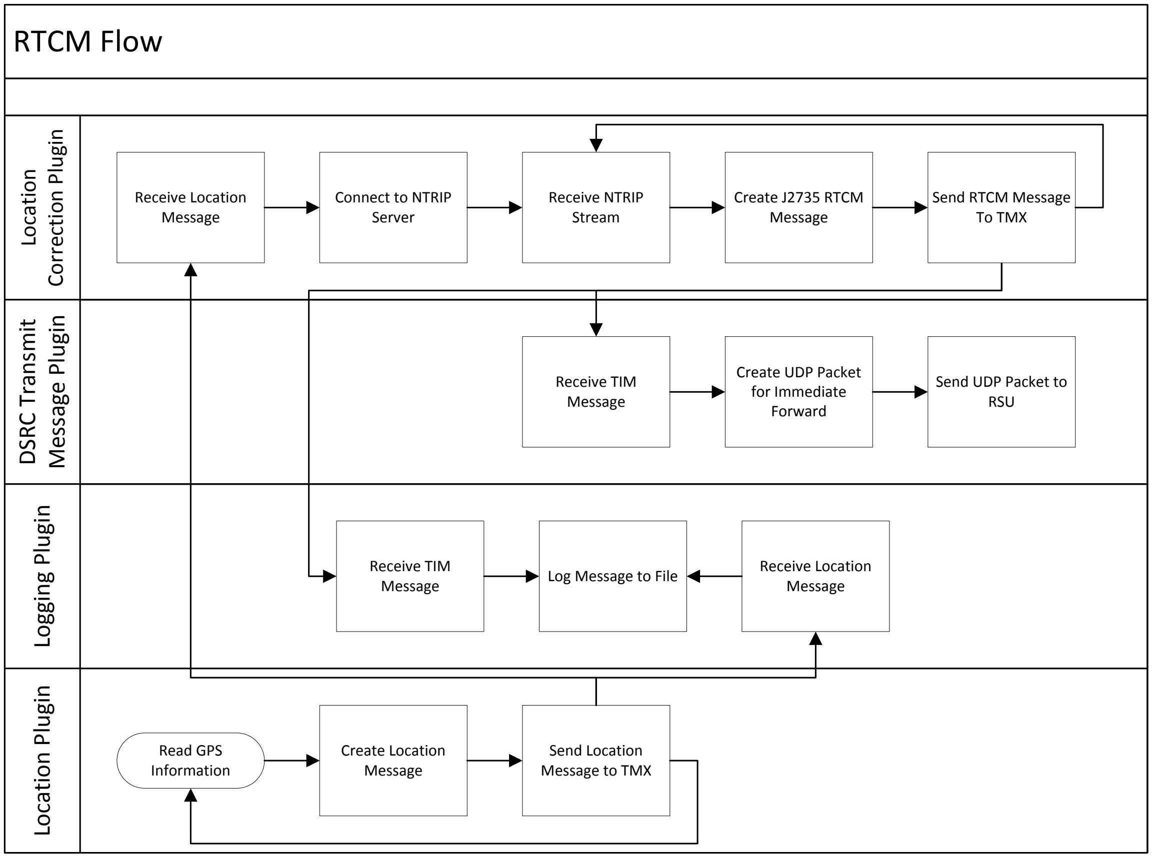


Figure 5-12 RTCM Message Data Flow

APPENDIX A. Terms, Definitions, and Acronyms

AREMA	American Railway Engineering and Maintenance-of-Way Association
C&S	Communication and Signals Manual
CONOPS	Concept of Operations
COTS	Commercial-Off-The-Shelf
CP	Computing Platform
DSRC	Dedicated Short-Range Communication
DVI	Driver Vehicle Interface
GID	Geometric Intersection Description
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IVP	Integrated V2I Prototype
MUTCD	Manual on Uniformed Traffic Control Devices
NTRIP	Network Transport of RTCM via Internet Protocol
OBU	On-board Unit (DSRC radio in VBS)
OEM	Original Equipment Manufacturer
OS	Operating System
RBS	Roadside-based Subsystem (an RCVW subsystem)
RCVW	Rail Crossing Violation Warning (warning message)
RSU	Roadside Unit (DSRC radio in RBS)
RTCM	Radio Technical Commission for Maritime Services
SPAT	Signal Phase and Timing
TIM	Traveler Information Message
TMC	Traffic Management Center
TMX	Transportation Message Exchange
TSC	Traffic Signal Controller
VBS	Vehicle-based Subsystem (an RCVW subsystem)
V2I	Vehicle to Infrastructure

APPENDIX B. Battelle Common Computing Platform Specifications

CPU	
CPU Name	Freescale i.MX6
CPU Type	ARM Cortex™-A9
CPU Cores	4; Quad-Core
CPU Clock (Max)	1GHz
Memory	
RAM	2GB DDR3
NOR Flash	2MB Serial NOR Flash
Multimedia	
2D/3D Graphics Acceleration	Vivante™ GC2000 Accelerated 2D and 3D
Video Encode / Decode	1080p60 H.264 Decode, 1080p30 H.264 Encode
Display	
HDMI	v1.4 1920 x 1080 - Type A
Networking	
Ethernet	10/100/1GB
Ethernet	10/100/1GB
Ethernet	10/100/1GB
Wi-Fi - External Antenna	LSR TiWi-BLE 802.11 b/g/n (Pre-certified)
Bluetooth	Bluetooth 2.1+EDR
	Bluetooth 4.0 (Bluetooth Low Energy)
CAN 1	ISO 15765-4, J1939
CAN 2	ISO 15765-4, ISO 14230-4 (Keyword Protocol 2000), ISO 9141-2 (Asian, European, Chrysler vehicles), SAE J1850 VPW (GM Vehicles), SAE J1850 PWM (Ford Vehicles), ISO 15765 ISO 11898 (raw CAN), GMLAN Single Wire CAN (GMW3089), Ford Medium Speed CAN (MS CAN), SAE J1939 bus interface, SAE J1708 interface
4G Cellular	4G/LTE Cellular PCIe
Power	

Automotive 12 V (13.6 V)	Continuous Input with additional 12 V input to transition to/from low power mode. External Power Button. 0.12 Watts in Low Power Mode
OS Support	
Linux	Ubuntu
Inputs/Outputs	
Isolated Analog/Digital/Discrete inputs and outputs	18 100mA variable drivers (8-bit Pulse Width Modulation), 2 12V Contact closure inputs, 2 analog inputs 0-5V 10 bit, 2 analog outputs 0-5V 10 bit, Header
Storage	
SATA	M.2 SATA connection for SSD
Audio	
Headphone	
Microphone	Analog MIC
Amplifier	2W Audio Amplifier
Connectivity	
Serial	232/485 DB9 connector. 2 additional on header.
SD	x1 microSD
USB	3 External
Environmental Specifications	
Industrial Temp	(-40C to +85C)
Other	
GPS	uBlox NEO-7P
DSRC	uBlox THEO-P1
Serial	232/485 DB9 connector. 2 additional on header.
Environment Specifications	
SAE J1211	-40 C to 85 C, Shock and Vibe
Water Resistance	EN 60529
Electromagnetic	SAE J1113, including procedures -2, -4, -11, -13, -21, -22, -26, -27, 41, 42j.
Dimensions (L x W x H) inches	11 x 8.5 x 5.5 (8 x 4 x 2)

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