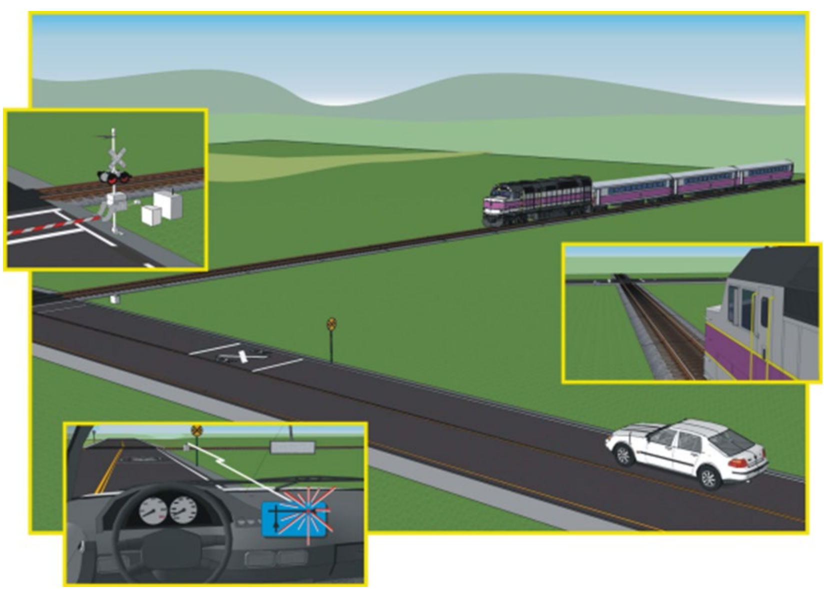
Vehicle-to-Infrastructure Rail Crossing Violation Warning – Phase 2

Architecture and Design Specifications

Final Report Rev. 2 — July 9 , 2020



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Architecture and Design document for the Rail Crossing Violation Warning – Phase II Project

14. ABSTRACT (Maximum 200 words)

This document describes the architecture and design for the Rail Crossing Violation Warning (RCVW) – Phase 2 safety application.

15. SUBJECT TERMS

Rail Crossing Violation Warning, V2I, Connected Vehicles, Design, Architecture, Safety Application, V2I Hub

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Revision History

Revision	Date	Change Description	Affected Sections/Pages
1	11/29/2019	Initial Release	All
2	7/9/2020	Revision to Include Updated GNSS Solution	Several throughout the document

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Chapter 1 Scope

This Architecture and Design Specification for the Vehicle-to-Infrastructure (V2I) Rail Crossing Violation Warning (RCVW) provides specifications that fulfill the following technical objectives as stated in Contract No. 693JJ618C000019:

- **Changes to make RCVW compatible with Institute of Electrical and Electronics Engineers (IEEE) 1570 serial signal preemption protocols for the Roadside-based Subsystem (RBS)**
  - Perform IEEE 1570 Interface Latency Requirement Check
  - Determine if IEEE 1570 Warning System Active messages are issued as quickly as the preemption status using a voltage-based interconnect.
- **Utilization of key vehicle status inputs from the Controller Area Network (CAN) Bus communications for the vehicle-based subsystem (VBS)**
  - Characterize the RCVW Global Navigation Satellite System (GNSS)-based position solution.
  - Determine if CAN-based speed and acceleration is better than GNSS-based.
- **Improved RCVW performance through additional vehicle-based position solutions**
  - Determine if inform and fault alerts, and warnings are issued in a timely manner.
  - Characterize nuisance factor across test scenarios.
  - Perform Dedicated Short-Range Communications (DSRC) Latency Requirement Check
  - Perform VBS Processing Latency Requirement Check
  - Determine if the position solution for RCVW II improved in regard to resilience.
- **The RCVW design, software, and hardware will be updated to meet current connected vehicle standards, such as Society of Automotive Engineers (SAE) J2735-2016; IEEE 1609.2, 1609.3,and 1609.4; IEEE 802.11p-2016; and RSU v4.1.**
- **The driver-vehicle interface (DVI) of the RCVW VBS will also be revised based on human factors study**

This document describes the architecture 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 RBS and VBS, and between the RBS and the existing rail grade crossing safety system leveraging the highway rail intersection (HRI) signal preemption connection, are also included. This document, together with the V2I RCVW 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

United States Department of Transportation (U.S. DOT)

"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 4.1 October 31, 2016

Vehicle-to-Infrastructure Rail Crossing Violation Warning ConOps

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

V2I Hub Design Document , March 2017

V2I Hub Interface Control Document (ICD), March 2017

Institute of Electrical and Electronic Engineers

IEEE 802.11p	2016 Standard for Information technology – Telecommunications and information exchange between systems Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications
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	2016 – Standard for Wireless Access in Vehicular Environments – Security Services for Applications and Management Messages
IEEE 1609.3	2016 –Standard for WAVE – Networking Services
IEEE 1609.4	2016 –Standard for WAVE – Multi-Channel Operation
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

Society of Automotive Engineers

SAE J2735	2016 Dedicated Short-Range Communications Message Set Dictionary
SAE J2402_201001	Road Vehicles - Symbols for Controls, Indicators, and Tell-Tales 2010-01-07

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 VBS installed in connected vehicles and a RBS integrated with roadside infrastructure at 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:

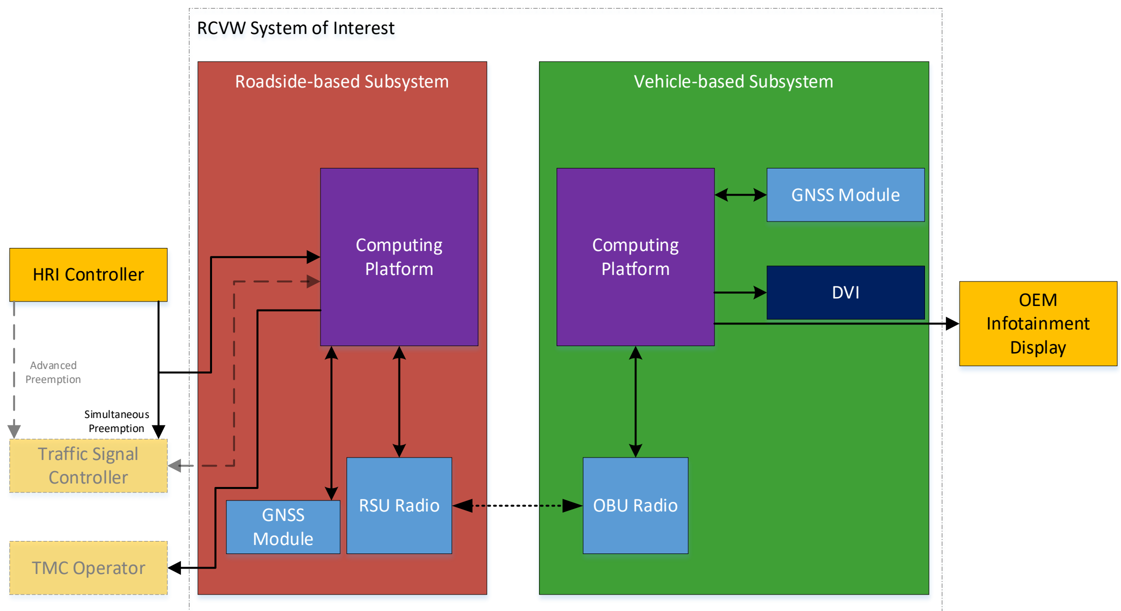
- Computing Platform (CP): The heart of the RCVW system are its CPs. CPs will control both RCVW subsystems. The V2I Hub software will reside within the RBS CP.
- DSRC Radios – the VBS and RBS will utilize DSRC radios (an OBU and an RSU, respectively) as a low-latency wireless communication method to connect the two subsystems.
- GNSS – A multi-band GNSS module with built-in RTK technology resides within the VBS to provide real-time lane-level position data. A similar device resides within the RBS to provide Radio Technical Commission for Maritime Services (RTCM) corrections to be broadcasted over DSRC.
- 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 such as the IEEE 1570 train detection messages will be accessed through their associated V2I Hub plugins. The V2I Hub software was developed for the Integrated V2I Prototype (IVP) project to support infrastructure communications for CV applications. V2I Hub is a singular communications platform with a set of integrated plugins to supply and receive information from deployed system components. The plugins utilized by the RCVW application include: HRI Status, MAP, DSRC Message Manager, Command, Message Receiver, RCVW, RTCM, Differential GPS and Vehicle Interface. Additional details on the V2I project and the plugins created can be found in the IVP Design and ICD documents. The V2I reference implementation project utilized 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. The RCVW system leverages the V2I Hub design and documentation. Supporting system documentation on the V2I Hub is available at www.its.dot.gov/code.

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, outputs, software, communications, and interface details are provided in the following sections of this document. Since the RCVW system was developed on top of the existing V2I Hub software and hardware that were completed on the IVP and V2I Hub projects, the design of the RCVW system is constrained to that of the system created by these projects. The V2I Hub plugin architecture can be found in the referenced V2I Hub Design document and V2I Hub 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. Administrative operations are available for a Transportation Management Center (TMC) operator; however, this requires a data connection to the RCVW CP.



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 V2I Hub software developed for connected vehicle applications under the IVP and V2I Hub projects. The V2I Hub software allows plugins to share information between each other in an V2I Hub system and broadcast information via a DSRC radio. Utilizing the V2I Hub will facilitate a reduction in deployment time and effort through use of plugins developed under the IVP and V2I Hub projects. The VBS will also use the V2I Hub 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 Signal Phase and Timing (SPAT), and GNSS to determine when an RCVW warning or alert will be presented.

Hardware

The hardware of the CP was chosen from the exiting commercial options. With the desire to use a common CP for both RBS and VBS RCVW systems, the basic requirements of the hardware were to support high-speed Ethernet, RS-422, Digital I/O, USB, high-speed CAN and DVI connectivity. Whereas the previous version of RCVW also required integrated Bluetooth, Wi-Fi, DSRC and/or cellular networking, this release simplifies the design of the CP by decoupling the necessary wireless communication, namely GNSS and DSRC, into external hardware models. The full specifications of the CP can be found in APPENDIX B.

DSRC Radio

The DSRC Radio transmits and receives messages in accordance with the IEEE 802.11p, 1609.2, and J2735 message standards. Communications to the RSU will be User Datagram Protocol (UDP) immediate forward-raw data payload messages as defined in the RSU 4.1 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 RTCM correction 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 RTCM correction message passes the differential GNSS information, including real-time kinematics (RTK), to be used for the VBS position solution. For more detail on the format of these messages, refer to the 2016 SAE J2735 DSRC 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=3081DE80011081090000000000000000100083010 1A481C63081C3800102A11BA119A01080
0418054A3B8104CE3585DF82020D068102004082010282 0207DB830306162184027D00850102A61
080041804FD888104CE35C39E82020CF68702016E880100A93C303A80020040A234A032A3300404
1C6BCDB304040420EC2B0404FAC8EC280404EF79F1210404EBC4FD660404E65310690404F9621
AA50404095B3F31AA3AA0383006A004800235293006A0048002010C3006A004800231383006A00
4800222113006A0048002010C3006A004800231483006A004800222118502100 1
```


Source: usdot-rsu-specification-4-1_final_r1.pdf, version 1, October 31, 2016, section 3.4.4

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
Signal Phase and Timing (SPAT)	0x8002	RCVW	MSG_SignalPhaseAndTiming	172
MAP message (aka Geographic Intersection Description)	0x8002	RCVW	MSG_MapData	172
RTCM correction	0x8000	RCVW	MSG_RTCMcorrections	172

Source: Battelle

GNSS Receiver

uBlox ZED-F9-, or similar, providing +/-1.5-meter accuracy.

Software

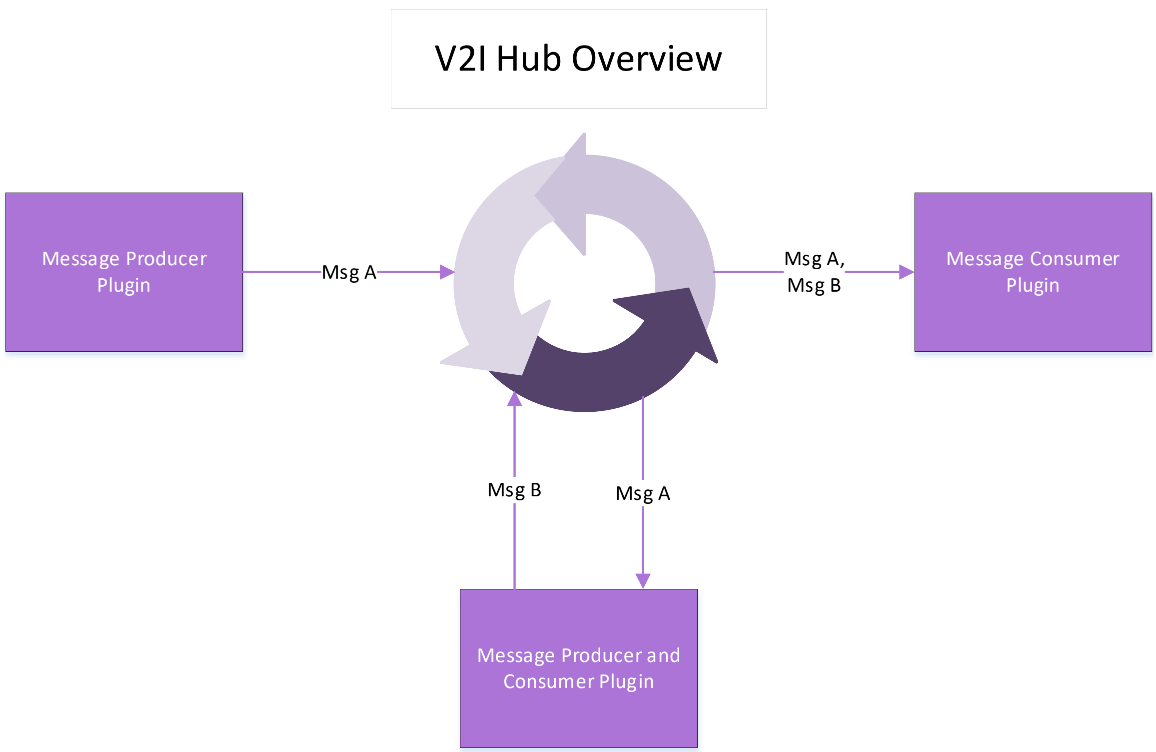
The Operating System (OS) selected for the CP is Linux as it allows a flexible platform for product development due to it being open source and easily customized.

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, V2I Hub, is described in greater detail below.

Linux

The OS running on the CPs is running version 16.04, which is built on 4.15.0-29 Linux kernel.

V2I Hub 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 V2I Hub platform. The V2I Hub platform was developed by Battelle to support the IVP project, and subsequently refined for use in the RCVW project. A high-level overview diagram of the V2I Hub platform is presented below in Figure 4-2.



Source: Battelle

Figure 4-2. V2I Hub Overview

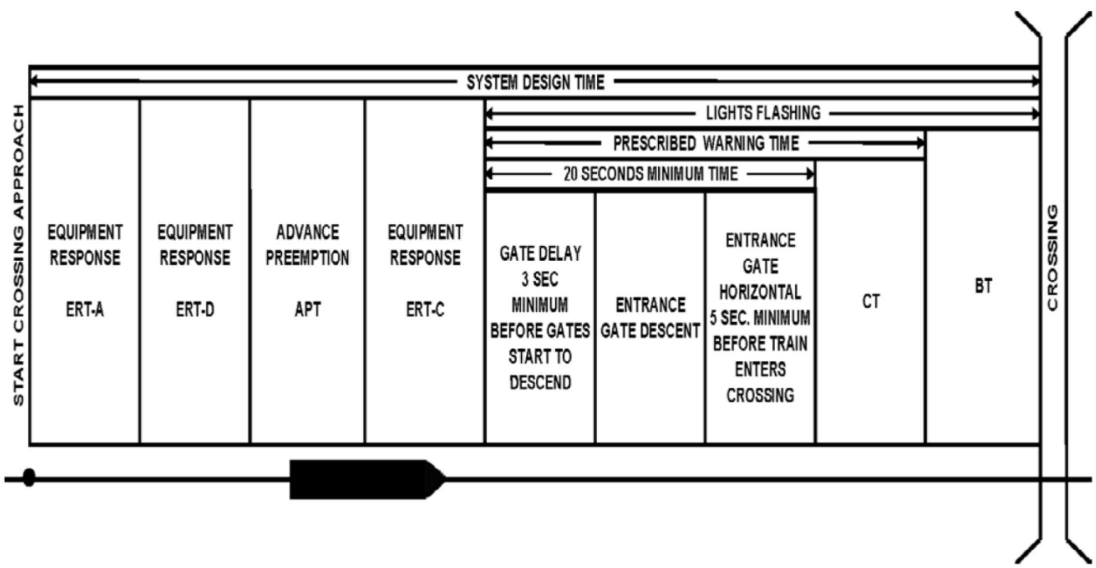
The system will be developed using the V2I Hub platform integrated with a set of loosely coupled plugins that communicate through the V2I Hub. Each plugin is responsible for registering with the V2I Hub. As part of registration, a plugin will notify the hub as to which message types the plugin will produce and transmit to the V2I Hub. Each plugin will additionally provide which message types it will request to receive from the V2I Hub. Plugins can be either message producers, message consumers or both. One key advantage of using the V2I Hub 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 specific warning messages. 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 versus 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 Communications &Signal 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. Refer to Section 1.2 of the V2I RCVW 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 (TSCs) at nearby intersections, a preemption signal is issued when an HRI is active. Code of Federal Regulations 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.

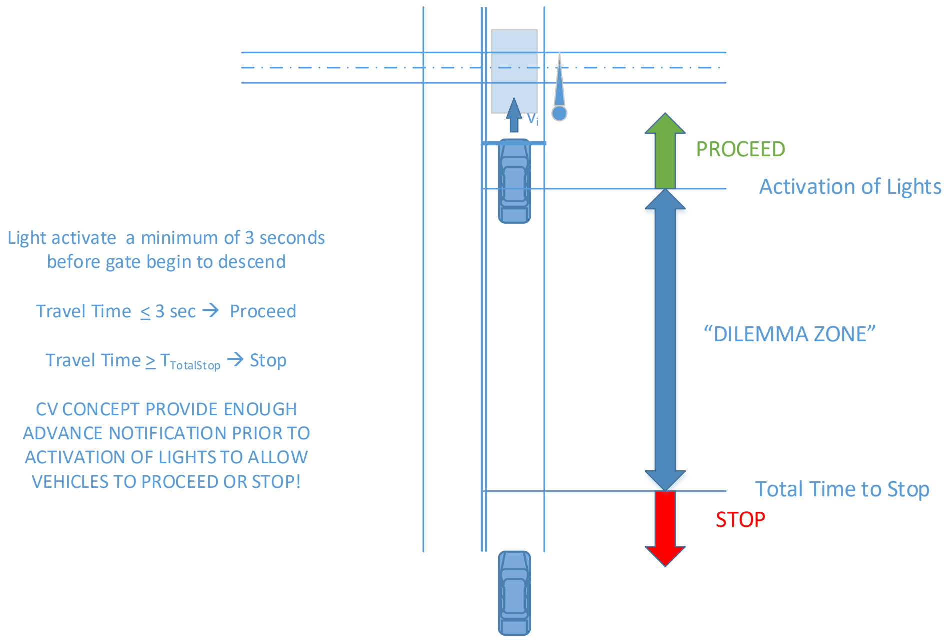


Source: AREMA Communications & Signal Manual

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"

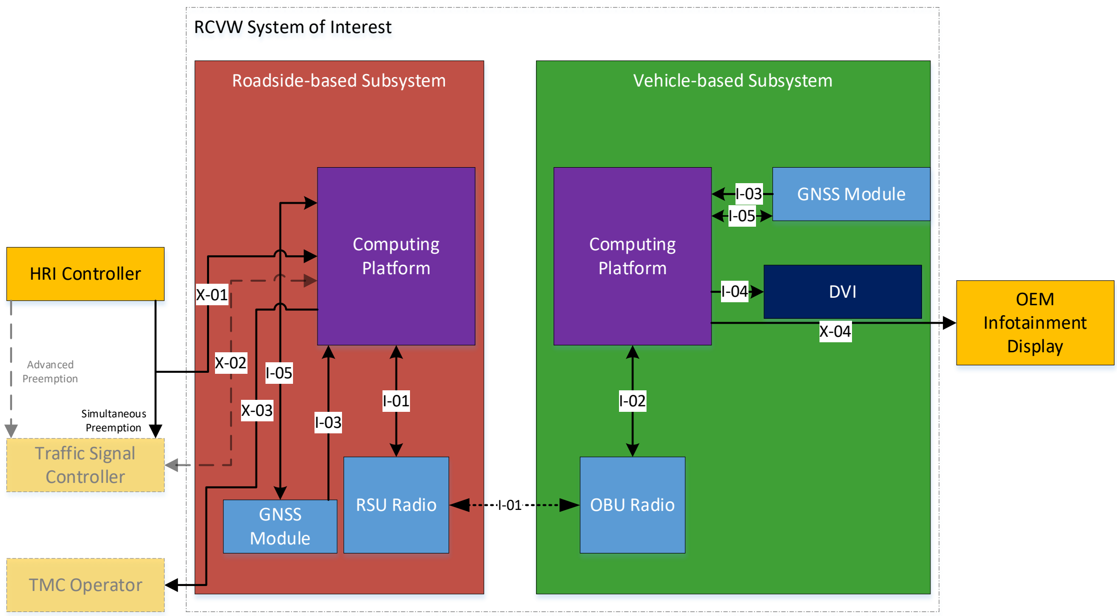
The VBS RCVW prediction algorithm will not change based on the availability of an advance preemption signal. The VBS RCVW algorithm will be conservative in that it will not calculate or issue alerts or warnings for vehicles to proceed within the HRI Approach Zone when the HRI is active, regardless of 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 and HRI status. Using the information provided by the RBS, the VBS determines when to provide informational and fault alerts and RCVWs.



Source: Battelle

Figure 5-3. RCVW System Overview with Interfaces

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

Table 5-1. RCVW System Interfaces

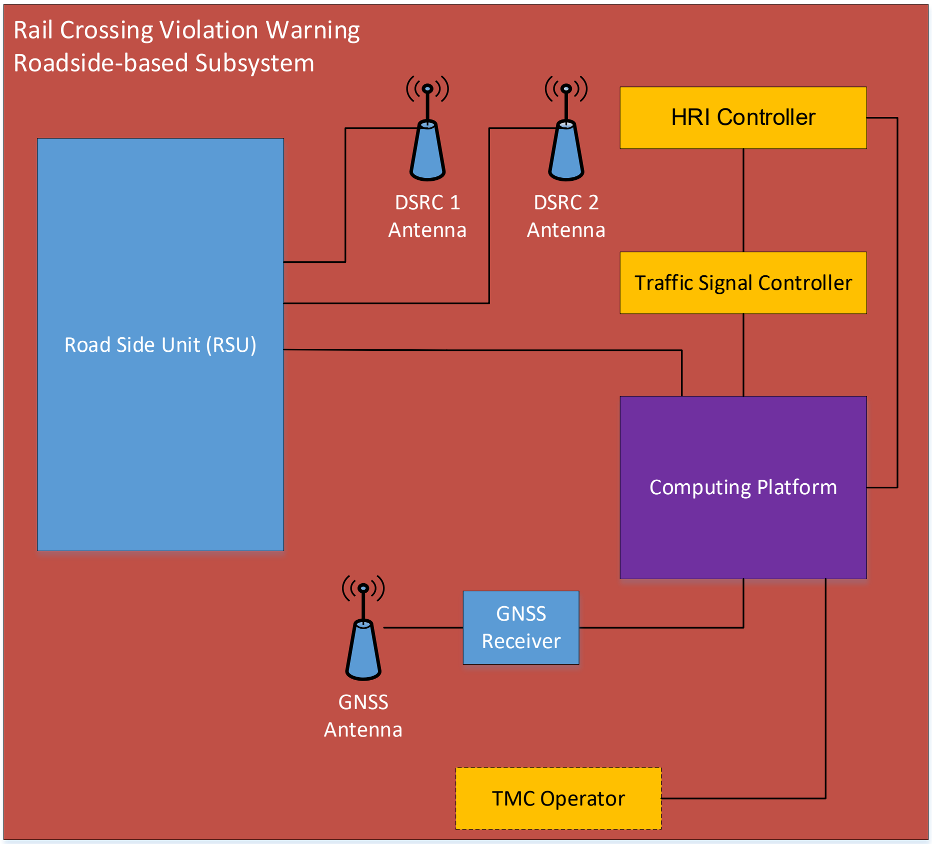
Interface Identifier	Interface Type	Exchanged information
I-01	DSRC	The RBS will send information to the VBS about the geographic layout of the HRI as a MAP message. The RBS will also send HRI status information to the VBS in a SPAT message, and RTCM Correction messages containing the differential GNSS correction. All messages are sent 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 GNSS radio to receive position and time information. This interface uses the Linux GPSD service daemon as a proxy for sending/receiving GNSS Data.
I-04	HDMI	The VBS will transmit warnings and alerts to DVI.
I-05	USB	The RBS and VBS will have a serial connection to the GNSS receiver to send and receive messages.
X-01	Preemption Signal	The RBS IVP CP will receive the HRI preemption signal directly from the HRI controller.
X-02	Signal Controller Status	The RBS 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-03	Internet / Cellular	The RBS will send failure notifications to a TMC Operator.
X-04	N/A	The VBS will integrate with existing infotainment systems to display the alerts and warnings on an Original Equipment Manufacturer (OEM) display. The interface to the OEM Infotainment System is vehicle specific.

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. RBS Hardware Block Diagram.

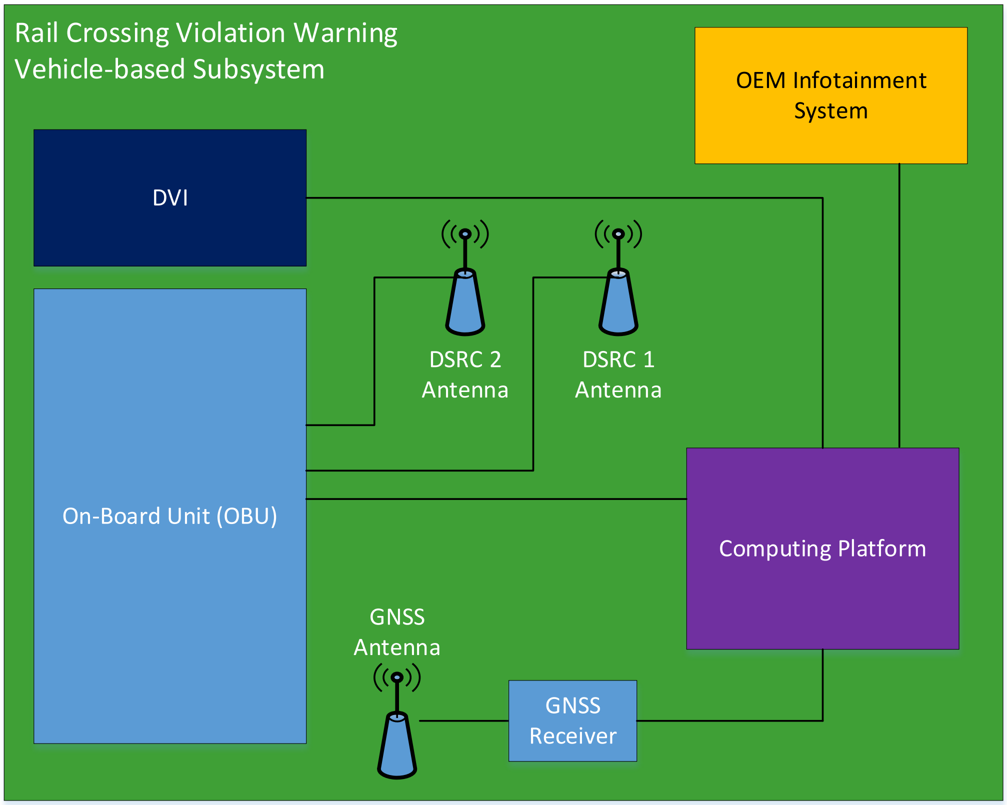
List of hardware to be provided includes:

- RCVW RBS
    - Computing Platform
    - DSRC Radio
    - DSRC Antenna 1 and DSRC Antenna 2
    - GNSS 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. VBS Hardware Block Diagram.

List of hardware to be provided includes:

- RCVW VBS
    - Computing Platform
    - DSRC Radio
    - DSRC Antenna 1 and DSRC Antenna 2
    - GNSS 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 V2I Hub 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 consists of 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 to 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 are transmitted from the RBS to the VBS via DSRC. The MAP for the HRI is generated manually by hand, ideally using the U.S. DOT ISD Builder Tool for SAE J2735.[2]

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 an alert or warning should be issued. The source for the HRI status may be a voltage detection circuit hard-wired to the existing rail loop detection system, or from an IEEE 1570 communication system.

The third is GNSS 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 GNSS must be

[2] https://webapp.connectedvcs.com/isd/#

sufficient to allow placement of the VBS within the lane information provided by the J2735 MAP message. The RCVW system utilizes a high precision multi-band RTK enabled GNSS module that provides a stable sub meter accuracy in optimal conditions.

The fourth input consists of vehicle speed and acceleration. Vehicle speed used by the VBS HRI algorithm in addition to other parameters when determining if RCVW warnings and alerts should be displayed, and the changes in speed, i.e. the acceleration of the vehicle, is used to determine if user action is sufficient to extinguish an active alert. The speeds can be acquired directly from the CAN network built-in to the vehicle, but alternatively are available from the GNSS receiver.

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 CP 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. Additional details on the CP are summarized in Chapter 4.

Driver Visual Interface

The DVI for displaying and annunciating RCVWs will be a commercial-off-the-shelf 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.

GNSS

The GNSS module will be used to determine the position of the VBS. The position accuracy of the GNSS must be sufficient to allow placement of the VBS within the lane information provided by the J2735 MAP message. The requirements document specifies +/-1.5 meters as the of GNSS accuracy to achieve lane-level accuracy for the VBS. The CP uses an uBlox ZED-F9P chip to obtain the needed level of GNSS accuracy. In addition to positional accuracy, the GNSS receiver must supply accurate heading information. The RCVW software algorithm automatically adapts to GNSS positional inaccuracies by “snapping” to a known near lane traveling in the same direction as the vehicle.

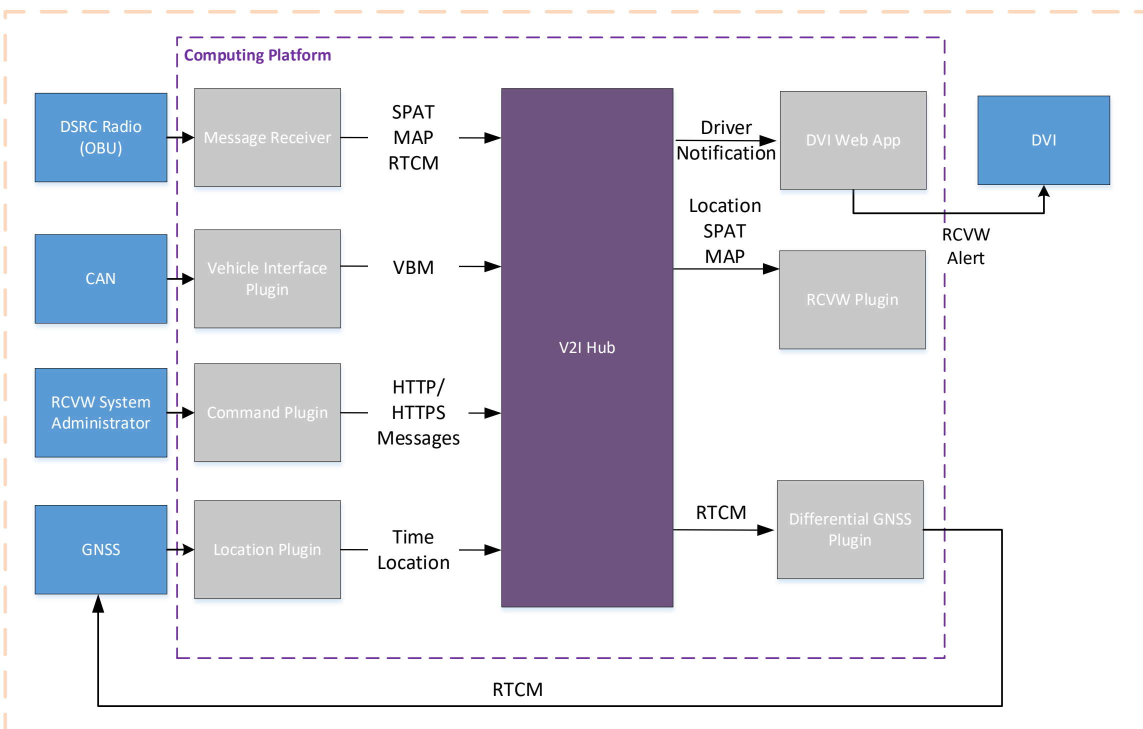
OEM Infotainment System

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. Interfaces to each OEM's infotainment system is vehicle specific.

Software

The software for the VBS will generate informational and fault alerts and RCVWs to the driver of a connected vehicle.

This RCVW application will be designed to interface with the V2I Hub 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. VBS Software Design

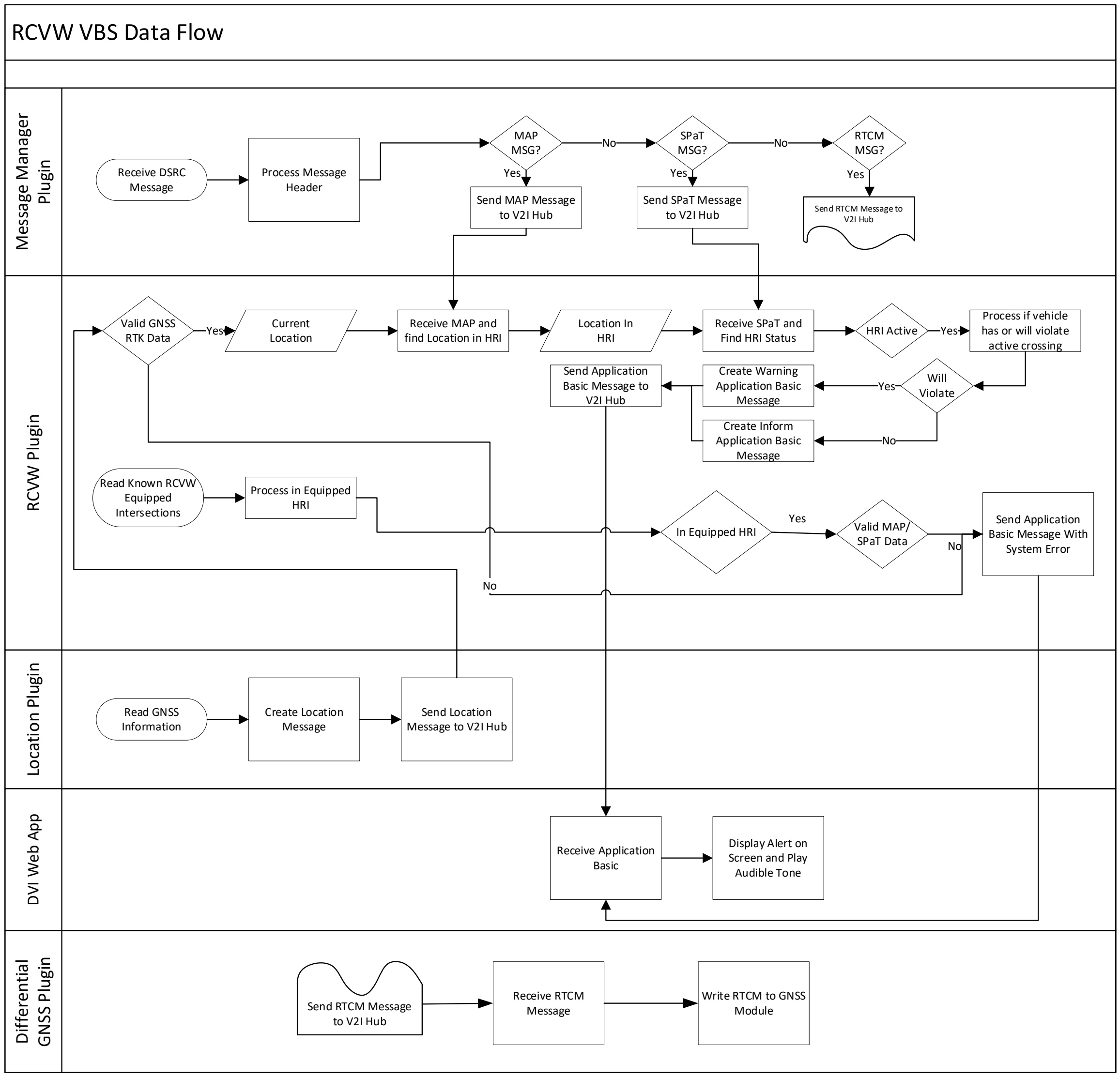
Table 5-2, below, provides a brief description of each plugin and its associated data exchange. The internal format of the messages is described in the IVP Design document's IVP JSON Message Structure section.

Table 5-2. RCVW System VBS V2I Hub Plugins

Plugin	Description	Plugin Input	Plugin Output
Location Plugin	This plugin will interface with the GNSS hardware and provide the current location and time information to the rest of the system.	Output stream from GNSS receiver	Location Message
Message Receiver Plugin	The DSRC Receive Message plugin relays messages received via the DSRC radio to the rest of the system.	Messages from DSRC Radio	SPAT Message MAP Message RTCM Message
DVI Web App	The Driver Notification web application will alert/warn the vehicle driver via visual and audible cues.	RCVW Warning RCVW Alert Clear HRI RCVW System Failure	Suitable audio output annunciated via DVI speakers Events shown on driver display
Vehicle Interface Plugin	The Vehicle Interface plugin will connect to the vehicle CAN network to access Vehicle Basic Messages (VBM).	CAN messages	VBM message
RCVW Plugin	The RCVW Plugin processes information from VBS support plugins and the CP to determine if and when to issue driver warnings and alerts.	SPAT Message MAP Message Location Message	Driver Notification Message
Command Plugin	Interfaces with V2I Hub administration portal.	HTTP/HTTPS messages	N/A
Differential GNSS Plugin	This plugin receives J2735 RTCM correction messages and passes the correction information directly to the GNSS receiver.	RTCM Message	N/A

Source: Battelle

Figure 5-7 below shows the applications and their data flow inside the RCVW VBS system. To simplify the diagram, the V2I Hub core message router is not shown. Plugins that produce and send messages to V2I Hub will have a line to the consumer of those messages. Additional details regarding the RCVW application for the VBS are described below.



Source: Battelle

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 V2I Hub platform. The Message Receiver plugin acts as the interface to the DSRC Radio and converts the received J2735 messages into a common format used by the V2I Hub platform. The differential GNSS plugin will correct the GNSS position using the correction data from the RTCM J2735 message. The DVI Web application 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.

Vehicle Interface Plugin

The Vehicle Interface 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 Vehicle Interface 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:

- CP to include:
  - Interface(s) to receive HRI status
  - Bi-directional interface(s) with roadway traffic controller(s) (if present)
  - GNSS

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 may be initiated by the preemption/train detection signal from the HRI controller.

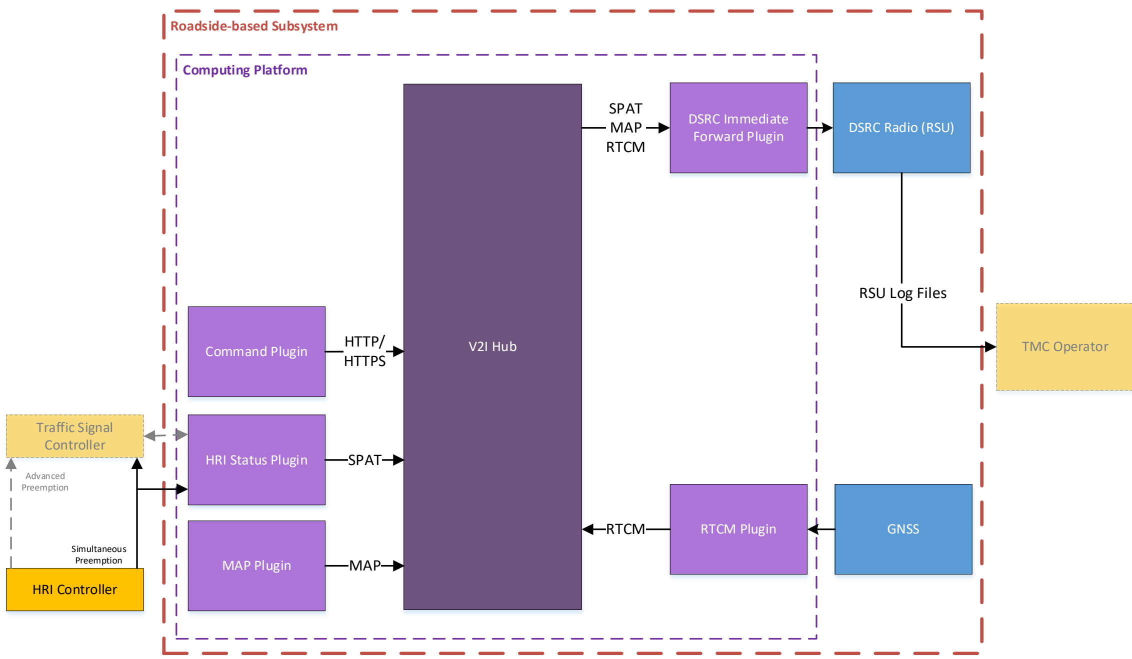
The suggestion connectivity is to use the built-in DB-15 DIO connector on the CP. Pins 1,2, 10 and 11 control the four-bit input word, along with pin 3 or pin 9 for ground. Input voltages vary between 5-24 V for a logic high and for 0-1.5 V for logic low. So, for example, by wiring in the positive voltage line to pin 1 and the negative to pin 9, the RBS HRI status plugin can be set up to detect the train by voltage on the first pin. Note that the configuration of the pin is zero-based (i.e. 0 is the first pin).

The default configuration for train detection is to use the IEEE 1570 protocol over a serial RS-422 interface. To do this, the RBS system must be connected to the IEEE 1570 infrastructure using a serial cable connected to the COM-1 port on the CP. This port should be configured to use RS-422 protocol. The HRI status plugin port name must be configured with the serial device name for COM-1, which should be /dev/ttyS0. If the port name is left empty, the system assumes that voltage detection is being used at the specified pin. If no device is connected at the port or at the DIO pin, then the RBS system will always assume that a train is present at the HRI.

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 and HRI status.

The RBS software will be designed to interface with the V2I Hub 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. Figure 5-8 provides a block diagram showing the design of the software.



Source: Battelle

Figure 5-8. RBS Software Design

The core plugins in the RBS provide situational information for the intersection. Both the MAP and SPAT plugins were developed for the V2I Hub 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 V2I Hub Plugins

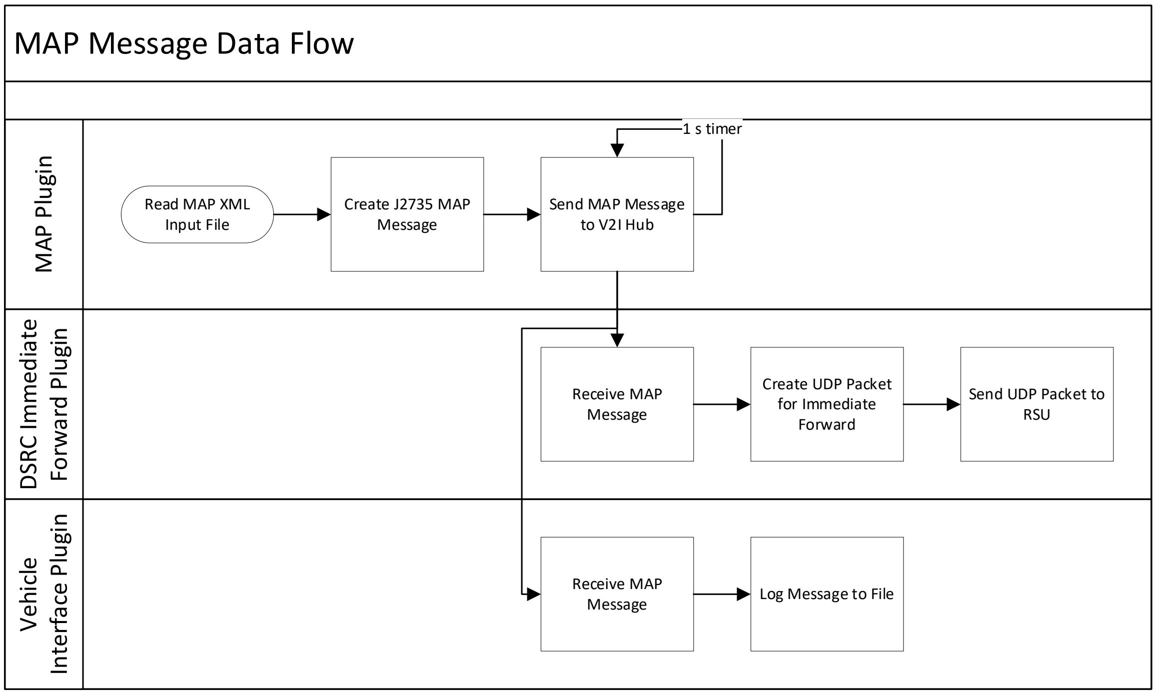
Plugin	Description	Plugin Input	Plugin Output
MAP Plugin	The MAP plugin will be responsible for generating the appropriate MAP message for the specific intersection.	HRI geometry loaded from filesystem	MAP Message
HRI Status Plugin	The HRI Status plugin is responsible for interfacing with the HRI controller and generating HRI Status messages containing the status of the HRI. The HRI Status plugin is also responsible for interfacing to the TSC.	Output from HRI signal controller	SPAT Message
DSRC Immediate Forward Plugin	The DSRC Immediate forward plugin is responsible for taking internal messages flagged for transmission and ensuring they are sent out via the DSRC radio.	SPAT Message MAP Message	Input to DSRC radio to send appropriate message
Location Plugin	This plugin will interact with a GNSS receiver and supply the system with location and time information.	GNSS NEMA Sentences	Time and Location Information
Command Plugin	Interacts with V2I Hub administration portal.	HTTP/HTTPS messages	N/A
RTCM Plugin	The RTCM Plugin is responsible for receiving GNSS corrections from a base station and creating the RTCM correction message	RTCM	RTCM Message

Source: Battelle

MAP and HRI Status Plugins

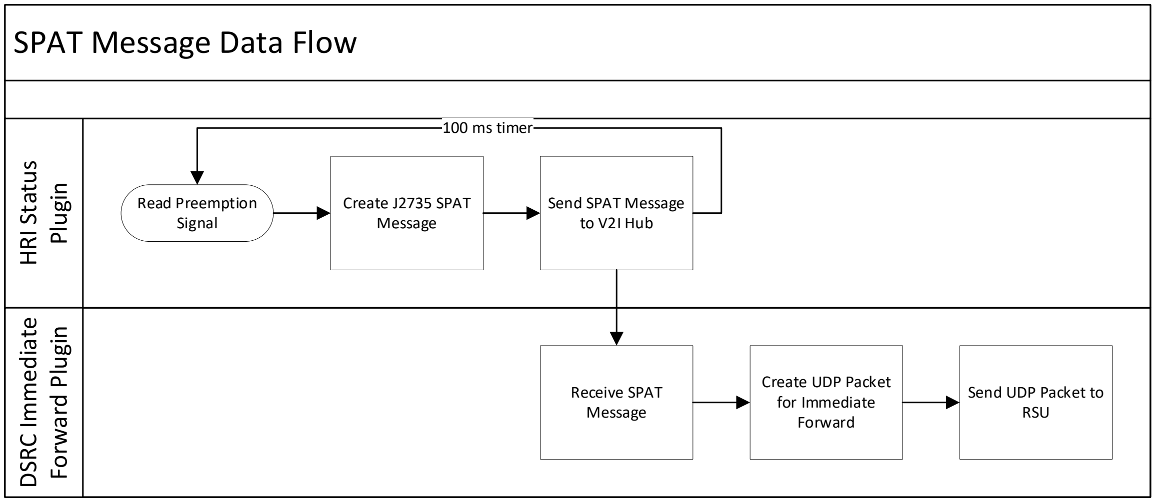
The MAP and HRI Status plugins work in concert to provide the information needed by approaching vehicles to determine whether a warning or alert should be issued given the current situation. The MAP message provides the geographic context for which the HRI Status Message information is applied. The content 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. Figure 5-9 and Figure 5-10 show the MAP and SPAT message flow in the RCVW RBS system, respectively.

If the HRI is not adjacent to a preempted highway intersection, the RBS will only produce HRI Status 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 HRI status 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 HRI Status message for the HRI contains the HRI active signal state as “event status”. The HRI Status message contains an intersection ID which will be used to correlate the HRI Status message to its MAP message. The VBS uses both MAP and HRI Status 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, the system will be using the event status “stop and remain” as the trigger for HRI active. Figure 5-10 shows the flow of the HRI Status message in the RCVW RBS system.



Source: Battelle

Figure 5-9. MAP Message Data Flow

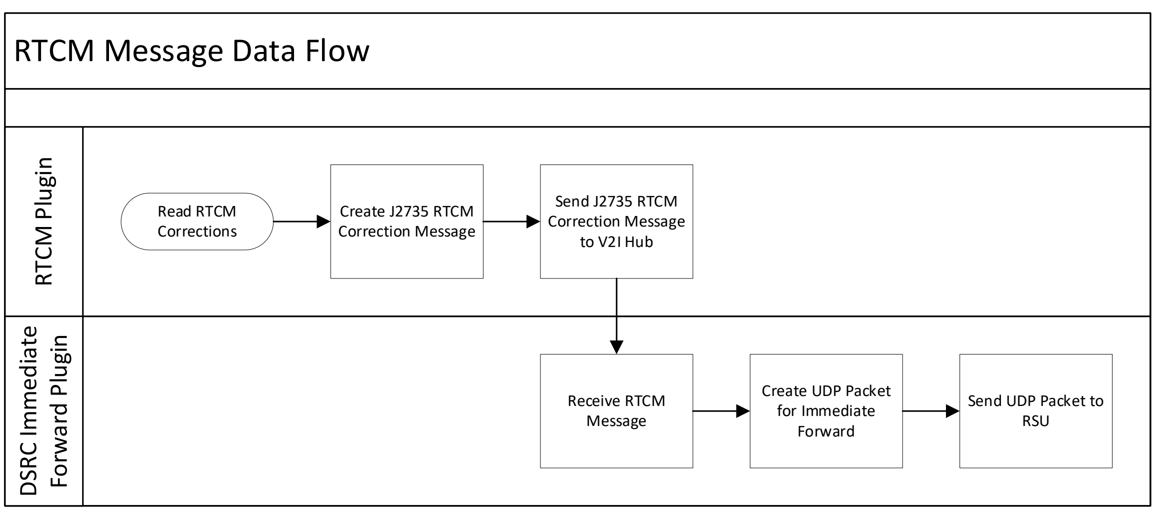


Source: Battelle

Figure 5-10. SPAT Message Data Flow

RTCM Status Plugin

The RTCM Plugin reads the RTCM corrections coming from the RBS GNSS module and creates a J 2735 correction message. The message is sent to the V2I Hub where the Message Manager plugin receives it, creates the UDP packet and sends it to the RSU for broadcast. Figure 5-11 shows the flow of the RTCM message in the RCVW RBS System



Source: Battelle

Figure 5-11 RTCM Message Data Flow

APPENDIX A. Terms, Definitions, and Acronyms

AREMA	American Railway Engineering and Maintenance-of-Way Association
CAN	Controller Area Network
CONOPS	Concept of Operations
CP	Computing Platform
DSRC	Dedicated Short-Range Communications
DVI	Driver-Vehicle Interface
GNSS	Global Navigation Satellite Systems
HRI	Highway Rail Intersection
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IVP	Integrated V2I Prototype
MUTCD	Manual on Uniformed Traffic Control Devices
NEMA	National Electrical Manufacturers Association
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
SAE	Society of Automotive Engineers
SPAT	Signal Phase and Timing
TMC	Traffic Management Center
TSC	Traffic Signal Controller
U.S. DOT	United States Department of Transportation
VBM	Vehicle Basic Message
VBS	Vehicle-based Subsystem (an RCVW subsystem)
V2I	Vehicle-to-Infrastructure

APPENDIX B. Neousys Intel CP Specifications

CPU	
CPU Type	Intel® Atom™ E3950
CPU Cores	4; Quad-Core
CPU Clock (Max)	1.6 GHz
Memory	
RAM	8GB DDR3L-1866
Networking	
Ethernet	10/100/1GB
Ethernet	10/100/1GB
Ethernet	10/100/1GB
CAN	1x isolated CAN 2.0 port
Power	
DC Input	8~35V DC
Input Connector	3-pin pluggable terminal block for DC input (IGN/ GND/ V+)
OS Support	
Linux	Ubuntu
Inputs/Outputs	
Isolated Analog/Digital/Discrete inputs and outputs	4x isolated DI 4x isolated DO
Storage	
SATA	1x half-size mSATA port 1x full-size mSATA port
Audio	
Headphone	3.5 mm headphone jack
Microphone	Analog MIC
Connectivity	
Serial	1x software-programmable RS-232/ 422/ 485 port (COM1) 3x 3-wire RS-232 ports (COM2/ 3/ 4) or 1x RS-422/ 485 port (COM2)
SD	x1 microSD

USB	2x USB 3.0 ports 2x USB 2.0 ports
Environmental Specifications	
Operating Temperature	-25°C ~ 70°C -40°C ~ 70°C (optional)
Storage Temperature	-40°C ~85°C
Humidity	10%~90% , non-condensing
Vibration	Operating, 5 Grms, 5-500 Hz, 3 Axes (w/ mSATA SSD, according to IEC60068-2-64)
Shock	Operating, 50 Grms, Half-sine 11 ms duration (w/ mSATA SSD, according to IEC60068-2-27)
EMC	E-Mark for in-vehicle applications CE/ FCC Class A, according to EN 55032 & EN 55024
Other	
GNSS	uBlox ZED-F9P
DSRC	Cohda MK5 OBU
Serial	422/485 DB9 connector. 2 additional on header.

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