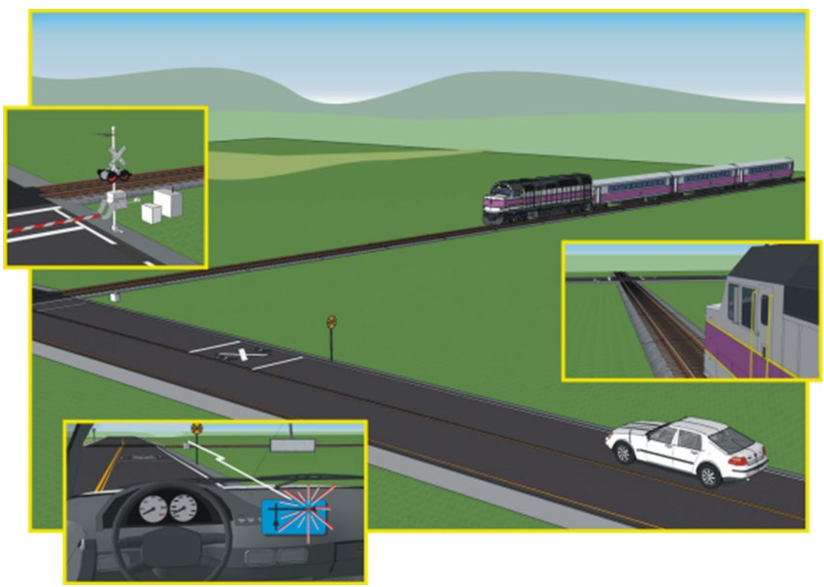
Vehicle-to-Infrastructure Rail Crossing Violation Warning – Phase 2

System Requirements Specification

Final Report Rev. 4 — October 19, 2020



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Anthony Polinori, Bohdan Paselsky, Alejandro Sanchez-Badillo

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System Requirement Specifications for the Rail Crossing Violation Warning – Phase 2 Project

14. ABSTRACT (Maximum 200 words)
This System Requirements Specifications (SRS) document describes the operational requirements for a Vehicle-to-Infrastructure (V2I) Rail Crossing Violation Warning (RCVW) safety application.

15. SUBJECT TERMS
Rail Crossing Violation Warning, V2I, System Requirements Specification, Connected Vehicles, Safety Application

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Acknowledgements

The HRI safety application addressed in this SRS is a variant of the system described in the CICAS-V SRS. Given the closely shared characteristics of the two systems, the content of the CICAS-V SRS was used as the basis for the development of this SRS. Many of the CICAS-V SRS requirements were adopted without modification. In some instances, the SRS requirements were modified, or new requirements were written to satisfy the unique characteristics of the RCVW system.

This RCVW Phase 2 SRS supersedes the SRS developed in the earlier phase of the project.

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Revision History

Revision	Date	Change Description	Affected Sections/Pages
A	09/20/2019	Initial Draft Release	All
B	10/9/2019	Final Release, incorporates FRA comments	Various
C	08/10/2020	Update due to change of GNSS Hardware solution	Various
D	09/25/2020	Addressed Comments from FRA/VOLPE	Various

Executive Summary

This System Requirements Specifications (SRS) document describes the operational requirements for a Vehicle-to-Infrastructure (V2I) Rail Crossing Violation Warning (RCVW) safety application.

The safety application, described herein, applies to freight, intercity-passenger, and commuter railroads with active crossing protection systems. The system provides a means for roadway-vehicles on approach to a highway-rail intersection (HRI) to be warned of a predicted violation of an active HRI. A warning, that is both timely and effective in alerting vehicle operators, who otherwise may be unaware of potential danger in their surroundings, is critical in the prevention of avoidable incidents. This document presents the requirements for an HRI safety application that is based on the U.S. DOT Connected Vehicle V2I concept by integrating the Connected Vehicle roadside architecture with track-circuit based, or other, train detection systems already in place at HRIs equipped with active warning systems.

The application may be deployed at any HRI where benefit would be accrued by increasing situational awareness to minimize safety related incidents or improving the flow of roadway traffic.

This SRS assumes that the HRIs being considered for inclusion in the RCVW program are currently protected by warning devices such as gates, bells, flashing lights, or wigwags that are activated by track-circuit based, or other, train detection systems.

The potential improvements offered by the HRI Connected Vehicle safety application are **safety, mobility,** and **environmental** related. The safety-related improvement is a reduction in the frequency and severity of HRI safety-related incidents cited in the safety statistics presented in Section 4.1 of the Vehicle-to-Infrastructure Rail Crossing Violation Warning Concept of Operations document.

Chapter 1 Introduction

The United States Department of Transportation (U.S. DOT) Connected Vehicle Program is "a multimodal initiative, the objective of which is to enable safe, interoperable networked wireless communications among vehicles, infrastructure, and portable personal communication devices to provide mobile related data services."[1] The suite of Intelligent Transportation Systems (ITS) incorporated within the Connected Vehicle Concept will improve safety and facilitate mobility within the National Transportation System. A "Vehicle-to-Infrastructure (V2I) Safety Applications for Highway-Rail Intersections" Concept of Operations (ConOps) was developed for ITS concepts at Highway Rail Intersections (HRIs) that are currently equipped with active warning systems. This System Requirements Specification (SRS) is based on that ConOps.

Chapter 1 of this document provides a basic concept of the RCVW system, HRI configurations where the RCVW system operates, definitions of RCVW zones and warning, and scenarios illustrative of the HRI configurations.

Chapter 2 summarizes the documentation referenced throughout the SRS. This includes CFR, U.S. DOT, IEEE, NEMA, SAE and Human Factors Guidelines documents.

Chapter 3 of this document provides a detailed description of functionality, design, and operation of the system, and associated requirements.

Chapter 4 provides a functional block diagram perspective of two of the three sub-systems, the third being a train detection system, required to achieve the objectives of the Rail Crossing Violation Warning (RCVW) system:

- RCVW Roadside-Based Subsystem (RBS)
    1. Roadside Unit (RSU) (i.e., DSRC radio in a RBS)
    2. V2I Hub computing platform running the RCVW roadside application
- RCVW Vehicle-Based Subsystem (VBS)
    1. On-Board Unit (OBU) (i.e., DSRC radio in a VBS)
    2. V2I Hub computing platform running the RCVW in-vehicle application
    3. Driver Vehicle Interface (DVI) (i.e., display and/or audible alert system)

The RCVW system design will be modular and extensible to facilitate the potential inclusion of future train detection technologies and Driver Infrastructure Interfaces (DII).

Chapter 5 provides a tabular summary of the RCVW system level, RBS, and VBS requirements. It additionally includes production unit requirements (PUR), which will not be addressed by the Phase 2 prototype that is developed.

[1]https://www.its.dot.gov/about.htm, accessed 9/18/2019.

System Purpose

RCVW is a V2I-based technology for HRIs equipped with active warning devices. When a connected vehicle with RCVW is approaching an active HRI (i.e., an HRI for which the HRI controller is receiving a preemption signal) the system will:

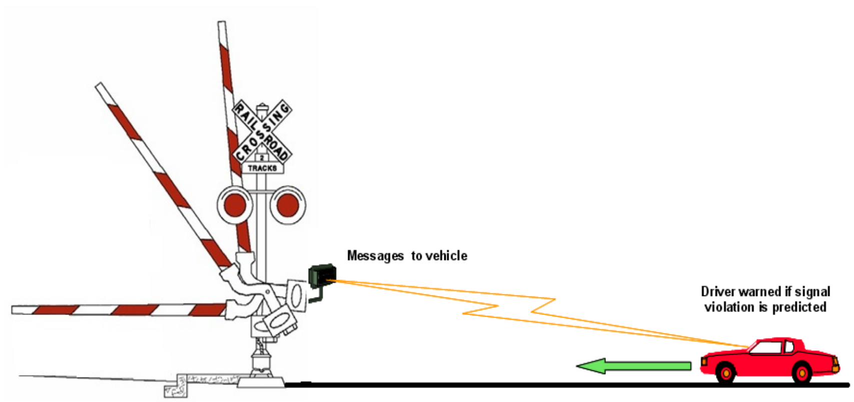
- Warn the driver of a connected vehicle if the VBS predicts the driver is not taking sufficient action to prevent a violation
- Alert the driver if the OBU is not receiving a broadcast from the RBS being approached

RCVW and Cooperative Intersection Collision Avoidance System for Violations (CICAS-V) are closely related.

An effective RCVW warning system is expected to:

- Reduce the number and severity of safety-related incidents at HRIs
- Reduce the cost of damages to infrastructure and vehicles.

Figure 1-1 illustrates the basic concept of the RCVW application.



Source: System Requirements Specification: Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V), Appendix C-2, Research and Innovative Technology Administration (RITA), 2008.

Figure 1-1. Basic Concept of RCVW at an HRI with RBS.

In the figure above, the connected vehicle approaching the HRI receives the following information:

- HRI Identification (ID) and RBS operational status
- HRI Active message, when appropriate
- Road elevation
- HRI configuration.

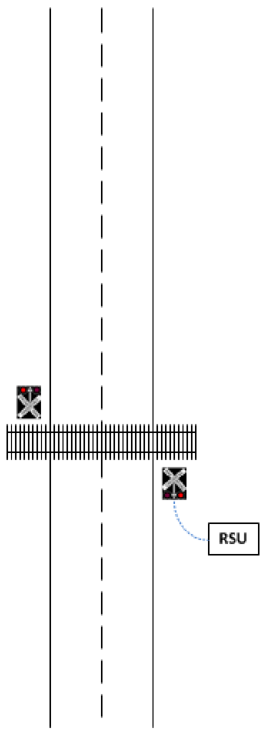
The safety and mobility applications in this SRS may require that VBS applications be developed or modified. The RBS applications for HRI safety are comparable, at least in part, to the CICAS-V applications.

Definitions

The following HRI configurations were considered in developing scenarios:

- HRI with no nearby intersection (Figure 1-2)
- HRI with a nearby intersection (Figure 1-3)
- HRI with nearby signalized intersection (Figure 1-4)

Note: *The HRI configuration illustrated in Figure 1-2 is the only configuration supported by the RCVW Phase 2 prototype system. The RCVW prototype can be adapted for other HRI configurations in future development.*



Source: Battelle

Figure 1-2. HRI with no nearby intersections.

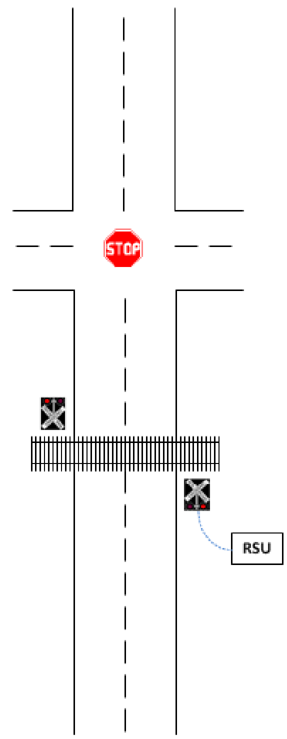


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Figure 1-3. HRI with nearby intersection.

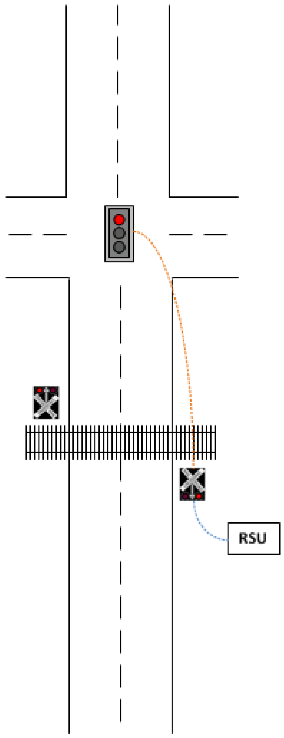

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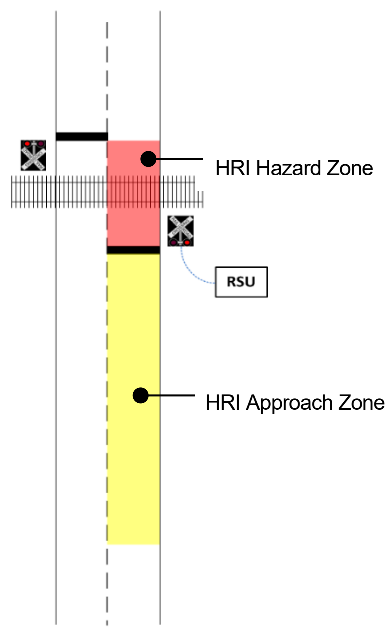
Figure 1-4. HRI with nearby signalized intersection.

The following zones define an HRI:

HRI Hazard Zone: The HRI Hazard Zone is the roadway between the stop bars on either side of the railroad track. The HRI Hazard Zone is in red in Figure 1-5 to the right.

- HRI Approach Zone: The HRI Approach Zone is the zone within which the VBS may issue warnings. Imminent collision 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 and communication and processing latencies, vehicle speed and roadway elevation. The HRI Approach Zone is in yellow in Figure 1-5 to the right.



Source: Battelle

Figure 1-5. HRI zones.

Note that each zone is direction specific. For illustrative purposes in this and all proceeding figures, only one direction of travel is considered.

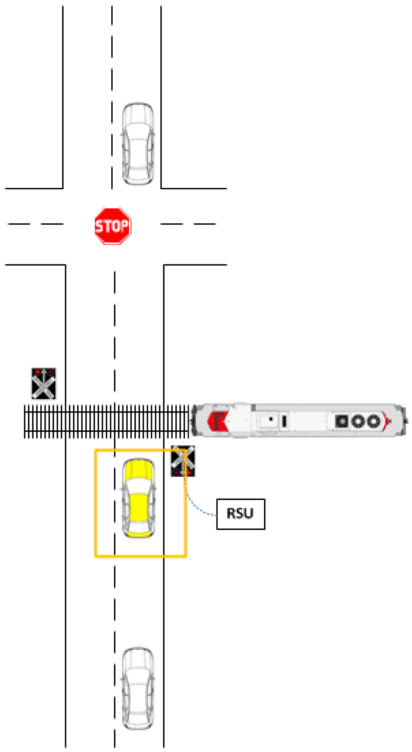
In normal operating conditions, the RCVW application produces two types of warnings:

- Rail Crossing Violation Warning (RCVW): When the HRI protection system is active due to a train being present, or approaching, and the RCVW application determines that the driver is not taking appropriate action to stop the vehicle, the VBS displays the RCVW. This type of warning is represented by the situation depicted in Figure 1-6.
- Clear HRI Warning: When the vehicle is within the HRI Hazard Zone and the vehicle operator is not taking action to clear the HRI Hazard Zone, the DVI displays a Clear HRI Warning message and audible alert to the driver – irrespective of HRI status. This type of warning is represented by the situation depicted in Figure 1-7.

  Note: *The standard guiding connected vehicle applications using wireless status messaging (i.e., SAE J2735) does not address designated railroad lane status (phase information) for vehicles not located within a recognized lane. Because of this, warnings for vehicles within the HRI Hazard Zone cannot be based upon crossing status. The RCVW Phase 2 prototype is, therefore, designed to issue a Clear HRI warning for vehicles stopped within the HRI Hazard Zone regardless of HRI crossing status. This protects vehicle operators who are breaking traffic laws as well as those who may be endangered by an impending train collision. In the future, when SAE J2735 provides better support for railroad-oriented applications to include definition of the zone within the intersection (in addition to the zones surrounding the interior of the intersection), the RCVW prototype design can be enhanced to recognize crossing status and provide more applicable alerts and warnings.*

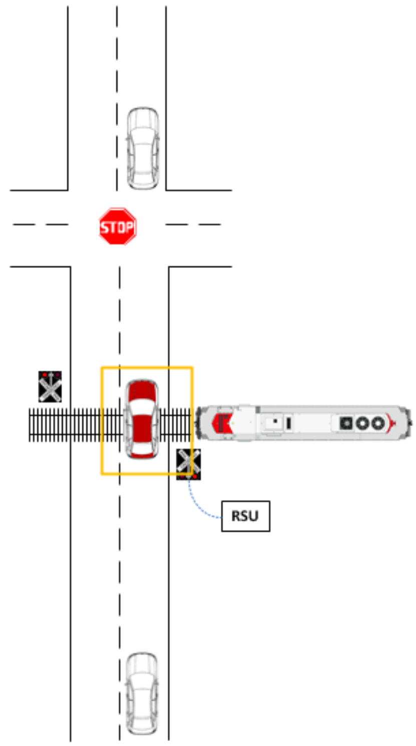
The DVI will not provide warnings prior to entering HRI Approach Zone or after departing the HRI Hazard Zone.

Note that Warning and Figure 1-7 are illustrative examples and not drawn to scale.



Source: Battelle

Figure 1-6. Rail crossing violation warning.



Source: Battelle

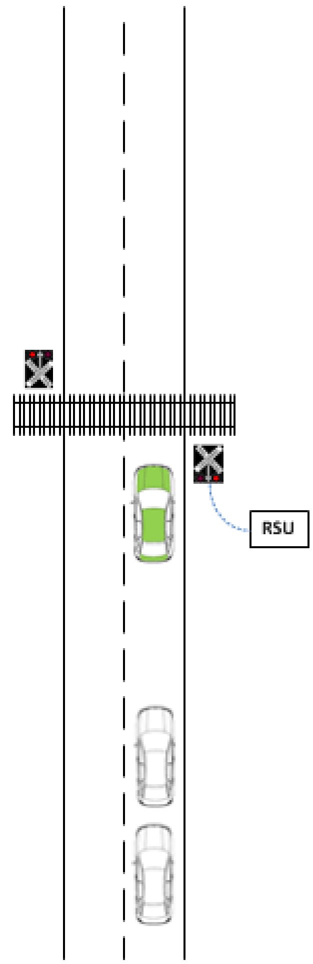
Figure 1-7. Clear HRI warning.

Scenarios

The following scenarios are illustrative of candidate HRI configurations considered, with variations of vehicle position relative to the HRI Hazard Zone and HRI Approach Zone. Many other configurations exist, but are excluded from this document because the types of alerts provided by the DVI are the same. All scenarios assume the system is operating normally. Startup/validation, system failure, and maintenance modes of operation are further discussed in Chapter 3 of this document.

Scenario 1: Vehicle Approaches an Equipped HRI; No Train is Present or Approaching

- A connected vehicle enters the HRI Approach Zone
- There is no train approaching or occupying the HRI; warning devices have not been activated
- The VBS DVI displays a fault alert if it fails to receive a broadcast from a “known” RBS

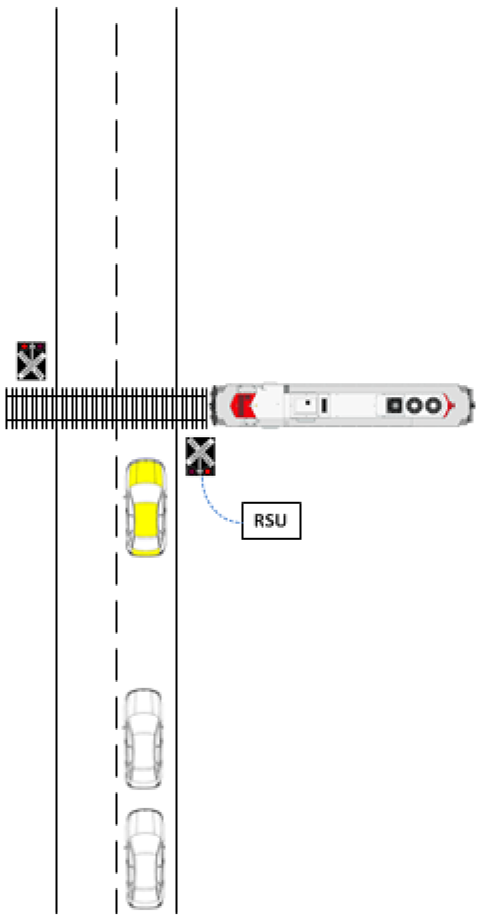


Source: Battelle

Figure 1-8. Scenario 1.

Scenario 2: Vehicle within HRI Approach Zone; HRI Protection System is Active or Becomes Active

- A connected vehicle enters an HRI Approach Zone
- A train is approaching or occupying the HRI; warning devices have been activated
- The DVI provides an inform alert
- If the driver does not react appropriately to prevent a predicted crossing violation, an emphatic warning shall be displayed by the DVI



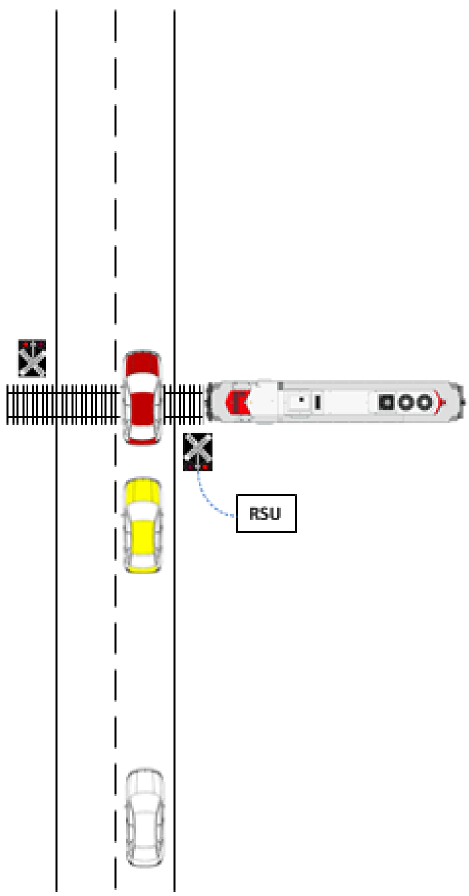
Source: Battelle

Figure 1-9. Scenario 2.

Scenario 3: Vehicle is Stopped within the Hazard Zone of an Equipped HRI; Train is Approaching

Note: For the RCVW Phase 2 prototype, a train does not need to be approaching or present.

- A connected vehicle is stopped within the HRI Hazard Zone
- A train is approaching, and warning devices have been activated
- The DVI issues a Clear HRI warning (crash imminent) that directs the vehicle operator to clear the HRI Hazard Zone immediately, with an indication to take aggressive action such as crashing through the gates if necessary



Source: Battelle

Figure 1-10. Scenario 3.

Acronyms and Abbreviations

This document may contain terms, acronyms, and abbreviations that are unfamiliar to the reader. A list of acronyms used in this document are included in APPENDIX A. APPENDIX B contains a glossary of terms.

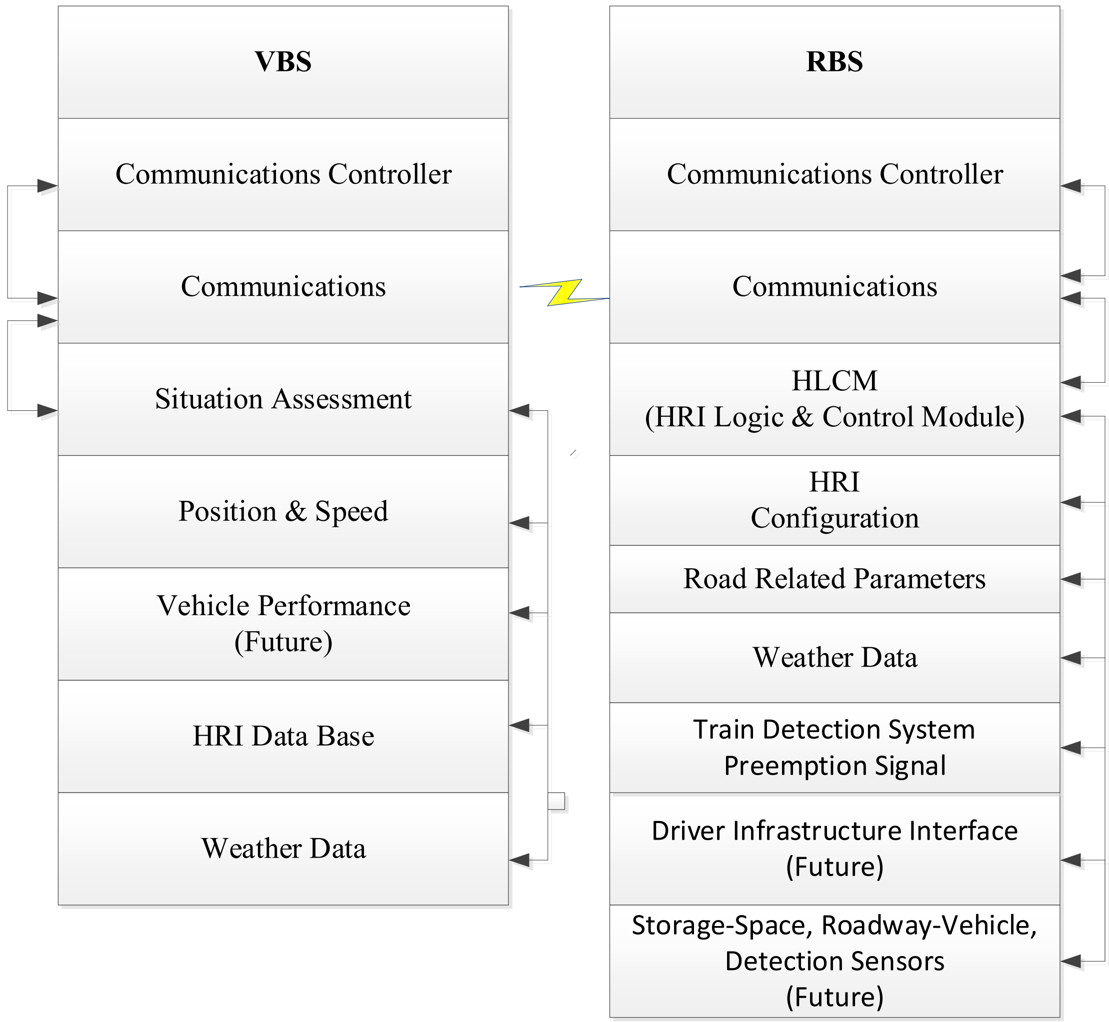
Acknowledgement

The HRI safety application addressed in this SRS is a variant of the system described in the CICAS-V SRS. Given the closely shared characteristics of the two systems, the content of the CICAS-V SRS was used as the basis for the development of this SRS. Many of the CICAS-V SRS requirements were adopted without modification. Some requirements were modified to satisfy the unique characteristics of the RCVW.

The ultimate objective of this approach is to facilitate the implementation of the RCVW application.

System Overview

The blocks in Figure 1-11 identify the functional elements and types of data/information necessary to achieve the objectives of RCVW. The intent of the block diagram is to suggest that the design be modular to accommodate insertions of future technology.



Source: John A. Volpe National Transportation Systems Center

Figure 1-11. Functional elements of RCVW.

Note: *The AASHTO Green Book-based warning distance formula used by the Phase 2 RCVW prototype system calculates a sight stopping distance-based warning and does not utilize weather data as an input.*

Chapter 2 Referenced Documents

Code of Federal Regulations (CFR)

- 49 CFR 236, “Rules, Standards, and Instructions Governing the Installation, Inspection, Maintenance, and Repair of Signal and Train Control Systems, Devices, and Appliances.”
- 49 CFR 236, “Positive Train Control Systems”, Notice of Proposed Rule Making
- [Docket No. FRA–2011–0028, Notice No. 1], RIN 2130–AC27.
- 49 CFR 234 “Grade Crossing Signal System Safety and State Action Plans.”
- 49 CFR 236.3 “Locking of Signal Apparatus Housings.”

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

- “Core System Concept of Operations (ConOps)”, US Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office.
- “Connected Vehicle Safety Applications For Highway Rail Intersections Concept of Operations”, US Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office.
- “System Requirements Specification: Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V)”, US Department of Transportation Research and Innovative Technology Administration ITS Joint Program Office.
- FHWA-RD-98-057 “Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO).”
- DOT HS 812 068 “Human Factors for Connected Vehicles: Effective Warning Interface Research Findings.”
- DOT HS 810 767 “Pre-Crash Scenario Typology for Crash Avoidance Research.”
- DSRC Roadside Unit (RSU) Specifications Document, Version 4.1 October31, 2016.
- DOT/FRA/ORD-12/22 “Driver Behavior Analysis at Highway-Rail Grade Crossings using Field Operational Test Data – Heavy Trucks”, December 2012.
- DOT/FRA/ORD-13/28 “Driver Behavior Analysis at Highway-Rail Grade Crossings using Field Operational Test Data—Light Vehicles”, May 2013.
- DOT/FRA/ORD-08/03 “Driver Behavior at Highway-Railroad Grade Crossings: A Literature Review from 1990-2006”, October 2008.

Institute of Electrical and Electronic Engineers (IEEE)

- IEEE 802.2 – 1998 Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks--Specific Requirements Part 2: Logical Link Control.
- IEEE 802.11 – 2012 Telecommunications and Information Exchange Between Systems Local and Metropolitan Area Networks--Specific Requirements Part 11: System Interface Module Specifications.
- IEEE 802.11p – 2010 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 Amendment 6: Wireless Access in a Vehicular Environment.
- IEEE 1233 – 1998 IEEE Guide for Developing System Requirements Specifications.
- IEEE 1483 – 2000 IEEE Standard for Verification of Vital Functions in Processor-Based Systems Used in Rail Transit Control.
- IEEE 1609 Standards for Wireless Access in the Vehicular Environment (WAVE).

National Electrical Manufacturers Association (NEMA)

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

Society of Automotive Engineers (SAE)

- SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary.
  - SAE J2945.1 Dedicated Short-Range Communications (DSRC) Vehicle BSM Communication Minimum Performance Requirements.
  - SAE J1757/1 Standard Metrology for Vehicular Displays 2012-08-20.
  - SAE J2402_201001Road Vehicles – Symbols for Controls, Indicators, and Tell-Tales 2010-01-07.

Human Factors Guidelines

- In-Vehicle Display Icons and Other Information Elements, Volume 1: Guidelines and Human Factors Design Guidance for Driver-Vehicle Interfaces.
- Human Factors Design Guidance for Driver-Vehicle Interfaces.

Chapter 3 System Description

System Context

Requirements applying to the entire system will be phrased: "The RCVW shall…" Requirements applying to RCVW infrastructure or vehicle components will be phrased: "The RBS components shall…" or "The VBS components shall…"

When an HRI protection system is active, the RBS shall transmit HRI status information ten times per second. This will permit the following warnings:

- When an equipped vehicle is within the Approach Zone of an active HRI, the RCVW application shall determine and warn the driver if appropriate action to stop the vehicle short of the HRI Hazard Zone is not detected.
- When an equipped vehicle is stopped within the HRI Hazard Zone the VBS DVI shall issue a Clear HRI warning (crash imminent) warning to clear the crossing immediately.

  Note: *The RCVW Phase 2 prototype cannot distinguish crossing status as noted in Chapter 1. In the future when crossing status can be distinguished the RCVW prototype can better inform and warn drivers of dangerous conditions and provide appropriate associated direction.*

When an HRI protection system is inactive, the RBS shall broadcast messages, once per second, that include the following:

- RBS operational status
- HRI Configuration Data File (HCDF)
- Road elevation

System Modes

The RCVW shall operate in one of four modes:

- Startup/Validation
- Normal Operation
- System Failure
- Maintenance.

The above modes are common to both the RBS and VBS components of the RCVW system. Common scenario examples for these modes are summarized in the Scenarios section above.

Major System Capabilities

The operational objectives of RCVW are dependent on the VBS and the response of roadway vehicle operators to RCVW alerts/warnings. RCVW provides the required data to the VBS to provide scenario appropriate alerts.

The RCVW requires normal operation of the following components:

- HRI controller (preemption signal)
- RBS
- VBS

RBS

RCVW functionality shall be compatible with all HRIs. The RBS shall communicate to the VBS an Active HRI (i.e., train present) message ten times per second starting at a minimum of twenty seconds prior to the train entering the HRI.

Operational State

The RBS shall function in one of two states: operational and *standby*[2]. If in a standby state, the RBS shall transition to an operational state upon:

- Sensing a DSRC signal.
- Receiving a preemption signal from an associated HRI controller.

During normal operation, Built-In-Self-Test (BIST) routines will be performed at least once per minute.

Standby State

If commercial power is unavailable, the RBS shall revert to a standby state:

- After the HRI controller deactivates the preemption signal, and if there is no OBU DSRC communication traffic.
- Five seconds after OBU DSRC signal(s) is(are) no longer detected.

In its standby state, the RBS shall execute BIST routines at least once per minute.

[2] The RBS operates in a standby state when commercial power is unavailable in order to minimize power consumption, thereby reducing the amount of battery backup required. ***Note:*** *The RCVW Phase 2 Prototype is optimized for low energy consumption in its design and logic. It is not designed to further lower its consumption based on the availability of commercial power. As a safety system that requires a powered active crossing signal, the vast majority of crossings with Active Warning Devices will possess commercial power. Future development of the RCVW system may explore practical methods of supporting remote grade crossings where power management is necessary.*

Message Types

The RBS shall broadcast messages that include, but are not necessarily limited to:

1. RBS operational status
2. HCDF – The HCDF shall include:
    - HRI geometry including the location of the stop lines
    - Revision level of the HCDF
    - HRI ID from the Federal Railroad Administration (FRA) HRI inventory system[3]
    - Road elevation

These messages shall be broadcast once per second.

Antenna Siting

The siting of the RSU DSRC antenna[4] must ensure adequate Line of Site (LOS) coverage to roadway vehicles. A roadway vehicle moving at the posted speed limit must have sufficient time to download the HCDF, execute safety applications, and allow the roadway vehicle operator to stop safely before arriving at the HRI.

Track-Circuit Based, or Other, Train Detection System

When the HRI controller is enabled by the train detection system it activates the protective warning devices and simultaneously provides a preemption signal, to any interconnected traffic signal controllers. This signal will notify the RBS that a train is approaching.

After the train has traversed the HRI the HRI controller will deactivate the protective warning devices and deactivate the preemption signal.

VBS

The VBS shall receive information from the RBS to permit the DVI to provide HRI-specific safety application alerts and warnings.

[3] The VBS uses the HRI ID to correlate its position to the HRI that it is approaching in the event that it receives simultaneous messages from more than one HRI.

[4] Some sites might require more than one DSRC antenna to ensure Line of Sight (LOS) coverage for all roadway approaches to the HRI.

Sequence of Events When a Roadway Vehicle Approaches an HRI

Table 3-1 provides a sample sequence of events as a roadway vehicle approaches an HRI.

Table 3-1. Sample action sequence at an HRI.

	HRI with RCVW
1	Vehicle approaches a RCVW-equipped HRI
2	The OBU receives HCDF from the roadside-based subsystem RSU
3	The vehicle-based subsystem determines its position relative to the HRI
4	When a preemption signal is provided by the HRI controller, the RSU transmits an HRI status message
5	If the vehicle-based subsystem determines that it is within the HRI Approach Zone and determines that the vehicle speed is excessive for the prevailing conditions, the DVI provides an RCVW warning
6	Driver reacts to the alert and takes appropriate action
7	Roadside-based subsystem RSU suspends broadcast of HRI status message when the HRI controller deactivates the preemption signal

Source: Battelle

Environmental Specifications

The RBS shall comply with all environmental requirements specified herein.

(The requirements cited below are from the DSRC Roadside Unit (RSU) Specifications Document)

a. Operating temperature: -34ºC to 74ºC.
b. Storage temperature: -45ºC to 85ºC.
c. Relative humidity: 95% condensing over the temperature range +4.4ºC to 43.3ºC.
d. Rain: The RSU shall pass the rain test with a rainfall rate of 1.7 mm/min, wind speed of 18 m/sec and 30 minutes on each surface of the device as called out in MIL-STD-810 G method 506.5 Procedure 1[5].
e. Salt fog: The roadside unit shall pass the salt fog test with 5% saline exposure for 2 cycles x 48 hours (24 hours wet/24 hours dry) as called out in MIL-STD-810 G method 509.5.
f. Wind: The roadside unit mounting bracket shall be able to withstand winds up to 150 miles per hour per AASHTO Special Wind Regions Specification.B19.
g. Operating shock and vibration: The RSU shall comply with MIL-STD-810G, Methods 514.5C-17 and 516.5 Shock and Vibration. (Testing shall be conducted in accordance with the procedures specified in IEC-60068 and IEC-60721.)

[5] DSRC Roadside Unit (RSU) Specifications Document provides a listing of all standards cited in section 3.5 by number and title.

h. Transportation shock and vibration (RSU packaged for shipment): The RSU shall comply with the United States Military Standard MIL-STD-810G, Test Method 514.6, Procedure I, Category 4. (Heavy truck profile) for packaging and shipping.)
i. Electromagnetic susceptibility: The RSU shall be immune to Radio Frequency (RF) Electromagnetic Interference (EMI) per SAE J1113.
j. Electrostatic Discharge RSU: The RSU shall be able to withstand electrostatic discharges from the air up to +/-15kiloVolts (kV) and electrostatic discharges on contact up to +/-8 kiloVolts (kV), in compliance with IEC EN61000-4-2.
k. Altitude: -60 to 3600 meters, referenced to sea level.

Major System Constraints

The RCVW design is based on technologies standardized by the ITS Connected Vehicle Program. As such, there are Connected Vehicle constraints that apply to RCVW:

- Radios shall use the Wireless Access in Vehicular Environments (WAVE) standards, based on the DSRC standard approved by the Federal Communications Commission (FCC) for use by automotive safety systems.
- The ITS Connected Vehicle radios shall transmit at a frequency of 5.9 GHz and have a nominal range of 1000 meters. The effective range will be reduced in environments where radio communications are affected by buildings, trees, other signal-blocking structures, or potentially by National Telecommunications and Information Administration (NTIA) restrictions, when within 75 kilometers of the Global Positioning System (GPS) coordinates listed in APPENDIX C .

Assumptions and Dependencies

Future implementations of RCVW will require the capability to correlate the position of four trains on two separate tracks (two trains per each track set) with respect to an HRI.

To achieve the objectives of RCVW, roadway vehicles must be equipped with ITS Connected Vehicle technology, and drivers must respond appropriately to in-vehicle alerts/alarms.

The overall effectiveness of RCVW depends on the roadway vehicle operator being able to respond to the warning appropriately and in a timely manner.

It is important to note that there are numerous factors, in addition to speed and distance from the HRI, that effect the ability of the roadway vehicle operator to stop safely:

- Physical capabilities of the roadway vehicle operator
- Situational awareness of the roadway vehicle operator immediately prior to the warning
- Road surface and elevation
- Weather as it affects braking distance

It is also important to note that vehicles traveling in excess of the posted speed limit may have less or inadequate time to be able to react to warnings.

Based on the Connected Vehicle concept, the RBS component of RCVW shall include the following:

- A WAVE radio system
- Industry standard unlicensed-band wireless transceiver(s)
- A process and control system capability that includes the following modules:
    - Industry standard wireless communication interfaces, e.g. IEEE 802.11, to enable remote access of RBS status and remote system resets as well as downloads of software updates
    - IEEE 802.3 communication interface to communicate with an on-site Maintenance Data Terminal (MDT)
    - HRI controller preemption signal interface

Operational Scenarios

The RBS component of RCVW shall have four operating modes: Startup/Validation, Normal Operation, System Failure, and Maintenance.

- The Startup/Validation Mode scenarios shall occur after the RBS has been installed.
- The RBS shall transition to the Normal Operation Mode after it has completed its Startup/Validation routine. In this scenario, all RCVW associated equipment and software operates normally when a roadway vehicle and/or train are approaching an HRI.
- RCVW shall transition to System Failure Mode when:
    - An RBS functional module fails a BIST routine
    - GPS data is not reliable (low accuracy and/or rate of reception) – regardless of reason
    - There is a detectable loss of connectivity with the HRI controller
    - There is a detectable loss of RBS communication of HCDF and/or HRI crossing status information
- Maintenance Mode scenarios affecting “normal” operation include corrective maintenance, RBS remote maintenance resets, software downloads, etc.

Note: *Maintenance Mode and Validation functionality at Startup have not been fully implemented in the RCVW Phase 2 prototype but are expected to be implemented in a future phase.*

Startup and RCVW Validation Scenarios

Conditions: *After the RBS has been installed in accordance with industry practices it is subjected to system validation testing. System validation testing will ensure accuracy and the integrity of communications between VBS-equipped roadway vehicles and the RBS before the RCVW is put “in service”. Maintenance vehicle-based subsystems shall be used for validating positioning accuracy, WAVE radio performance, and the timeliness and integrity of the messages.*

Once the RBS has been installed at an HRI, it is set to Validation Mode. During its approach and crossing of the HRI the maintenance vehicle will acquire and record data for subsequent analysis. The RBS will remain in Validation Mode until all validation tests are successfully completed.

The specific types of data collection that will be performed as part of the validation process include the following:

- **Coverage Validation Data:** The VBS of the maintenance vehicle shall acquire and record RSU transmitter signal strength as well as associated communication performance statistics at a site-specific-number of points to ensure the radio coverage specification is satisfied.
- **Positioning Validation Data:** The maintenance vehicle-based subsystem shall approach and cross the HRI comparing the position data that it is acquiring with relevant HRI infrastructure locations. If the correlation is acceptable, ± 1.5 meter(s), it shall communicate the positioning correction data to the RBS.

While approaching the HRI at the posted speed limit the maintenance VBS shall receive the simulated HRI status message. The time that the maintenance VBS displays the alerts shall be recorded and subsequently correlated to the maintenance vehicle VBS derived coordinates when the alert information was triggered. The timing of the alerts shall provide sufficient time for a roadway vehicle operator to stop safely.

Once the requirements to put the RBS "in service" are met, the responsible organization will change the RCVW from Validation Mode to Normal Operation Mode.

Normal Operation Scenarios

Normal operation includes scenarios in which the RCVW is not in Startup/Validation, System Failure, or Maintenance Mode, and in which the RCVW equipment is performing normally. The configurations, scenarios, and associated alerts for equipped HRIs are described above. In each of these scenarios, the state of the driver is unknown. The driver may be attentive, inattentive, distracted, incapacitated, or impaired. The driver may have the intent to obey or violate the HRI warning devices that he or she is approaching.

System Error and Failure Scenarios

This section describes some of the scenarios that may occur when various aspects of the system fail to operate.

HRI Configuration Data File (HCDF)

HCDF errors mean that the geospatial data the VBS receives from the RBS may be obsolete or does not accurately reflect the geometry of the HRI. When this occurs, the VBS may issue a false warning or may not produce a warning in time.

Communication Errors

Communication failure means that the VBS does not receive some or all messages from the RBS. The cause of the communication failure may be due to the RBS or its RSU, the VBS or its OBU, or interference from temporary radio-blocking objects (e.g., a large truck) in the area. The discussion below addresses the situation where the communication problem lies with the RBS.

Geospatial Information

Geospatial Information related faults relate to the accuracy of the calculated vehicle position as well as the rate this information is received by the VBS. When any of these situations occur, alerts and warnings will not be issued at the right time and location and false warnings and alerts can occur.

Maintenance Scenarios

Conditions: When the RBS is “in service” a BIST is triggered automatically once per second. This is in contrast to Validation Mode testing where manual intervention is required to initiate testing and subsequently required to return the system to “in service” status.

The accuracy of the HCDF, WAVE radio communication system performance, and message integrity, must be periodically verified.

Note: *Although full Maintenance and Validation functionality is not available in the RCVW Phase 2 prototype, partial functionality that addresses system resilience is. For example, the BIST plugin verifies that V2I Hub core software is executing and that the enabled plugins are functioning. The BIST function also verifies RSU operability by transmitting and receiving test messages, and monitoring RSU transmission power levels. When the RBS detects a failure, the BIST function automatically takes the RBS “out of service”. The V2I Hub watchdog attempts to recover when errors are discovered. Future iterations of the RCVW BIST function will report failures to a maintenance facility.*

Chapter 4 Functional Block Diagram

A functional block diagram provides system developers and developers of other interfacing systems with an overview of the applications (software modules), including program objectives, interactions, and interfaces that comprise the system. System designers will use this perspective to design each module so that it performs its required function. Each requirement in this specification will be allocated to one or more of the modules described in this perspective.

The modules identified in this perspective are only intended to be representative. The modules are based on the functional requirements of the system. In the final design, these modules may ultimately be divided into smaller ones to allow for the assignment of specific tasks to a specific module, the reuse of existing code from other sources, or for the optimization of software program development.

VBS

The VBS is described/specified in detail in Appendices C-1 and C-2 of the CICAS-V Phase I final report. Information that pertains to RCVW is presented herein to describe the context in which RCVW is likely to be implemented. Figure 4-1 presents the adaptation of the CICAS-V VBS to RCVW. This SRS does identify revisions to VBS software programs that are necessary to implement RCVW.

The safety application for RCVW is logically equivalent to a traffic control signal interfaced with an RBS, with modifications to the DVI message.

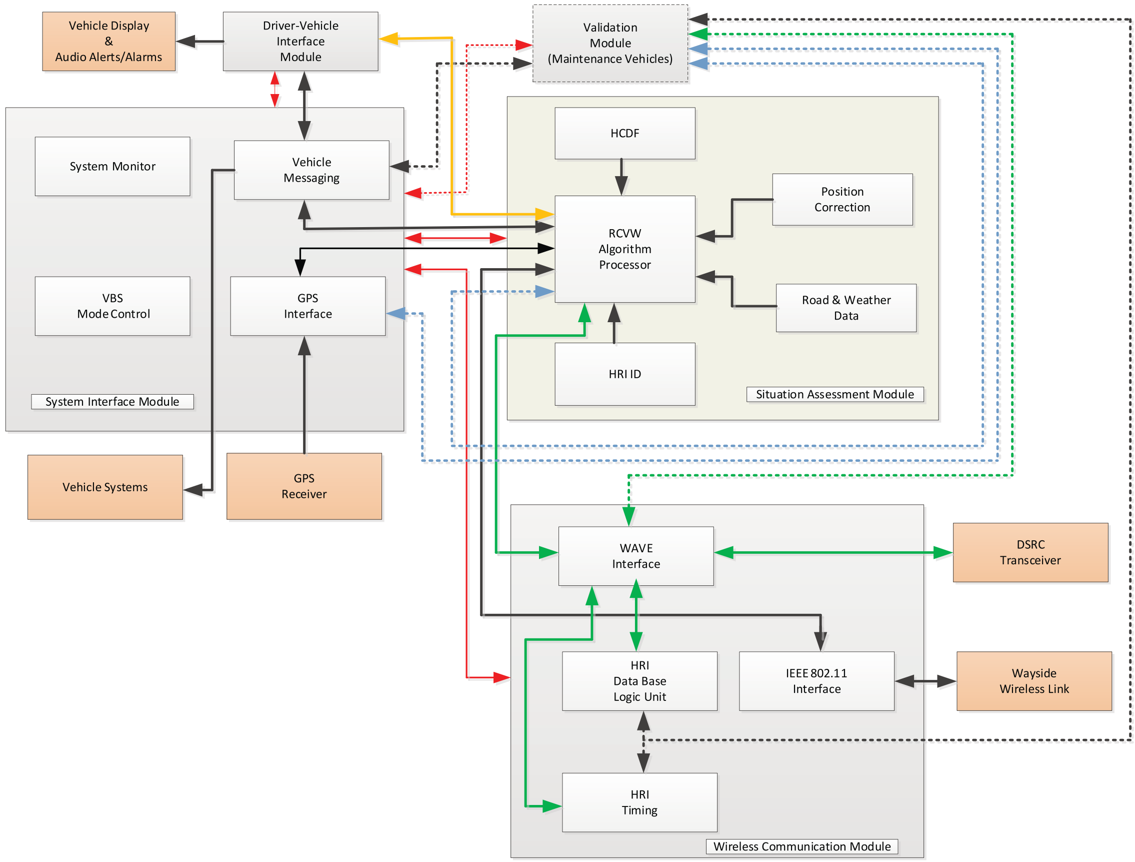
As shown in Figure 4-1, the VBS is comprised of the following functional modules:

- Wireless Communication Module (WCM)
- VBS Validation Module (VVM) – required for maintenance vehicles
- Situation Assessment Module (SAM)
- System Interface Module (SIM)
- DVI Module (DVIM)

System Interface Module

The SIM is the first module to be initialized when a vehicle is started and is responsible for wired communications between the VBS and all other physical in-vehicle devices. Upon startup, the SIM determines the proper operational mode for the VBS and transmits it to the other modules, as functionally represented by the “VBS Mode Control” block in Figure 4-1. Once operational, it periodically monitors the other VBS modules by requesting status and initiating corrective actions when necessary, as functionally represented by the “System Monitor” block in Figure 4-1. When a status message is received indicating an abnormality, or there is no response to the request, it initiates corrective actions.

For RCVW the SIM will manage the flow of messages between the SAM and the DVIM. The DVIM will "echo" messages back to the SIM. The SIM will send the "echoed" messages to the RBS, via the WCM, where they will be stored for 48 hours.



Source: Final RCVW V2I SRS May 2016

Figure 4-1. Adaptation of CICAS-V VBS for RCVW

Note: *As noted above, Validation functionality has not been fully implemented in the RCVW Phase 2 prototype.*

Wireless Communication Module

The WCM will provide the wireless link to/from the RBS. The functional requirements of the WCM will be those stipulated in the IEEE suite of protocols addressing WAVE and DSRC specifications.

The WCM is initialized after receiving a signal from the SIM and will execute a BIST after it is initialized. During normal operation, BIST routines will be performed once per second. If a failure is detected, the WCM will report it to the SIM when polled. The WCM will respond to status inquiries from the SIM with a message that indicates "normal function" or "failure detected". The information flow for transmitted messages is:

SAM →SIM→WCM→ DSRC radio.

Received messages will follow the reverse information flow and be authenticated in accordance with the WAVE protocol standards.

When the WCM receives the “echo” of a message sent to the DVIM by the SIM, the message will enter the WAVE protocol stack. The message will pass from layer to layer until it reaches the physical layer and is transmitted by the OBU.

Situation Assessment Module

The SAM is the processing element of the VBS. The SAM as it applies to RCVW will determine roadway vehicle:

- Speed
- Braking effectiveness
- Location with respect to the HRI

Braking effectiveness is a function of factors such as:

- Road surface conditions and elevation
- Roadway vehicle performance specifications

The SAM will be initialized by the SIM. The SAM will execute a BIST routine after initialization. During normal operation, BIST routines will be performed once per second.

The SAM will validate RCVW-specific applications. An unsuccessful execution of the validation routine will be followed by a second attempt. If the validation routine fails the second attempt, the SAM will transition to failure mode. The failure will be reported to the SIM when polled.

The SAM will respond to a status inquiry from the SIM with a status message that indicates either “normal function” or “errors detected.”

When a roadway vehicle is within DSRC range of an RBS in its database, the SAM expects to receive RBS broadcasts. If an RBS broadcast is not received, an error message is generated.

While approaching an HRI, the SAM will receive an HCDF from the RBS. If it does not receive one, it shall retrieve a generic one from memory.

Using the above information, the SAM will determine the likelihood of a roadway vehicle entering/crossing an HRI in violation of a RCVW. If it is predicted that a violation is about to occur, the SAM will issue a warning via the VBS DVI.

Driver-Vehicle Interface Module

The DVIM, which is initialized after receiving a signal from the SIM, will control the DVI display, audio, and/or haptic devices. The DVIM will execute a BIST routine after being initialized. During normal operation, BIST routines will be executed once per second. If a failure is detected, it is reported to the SIM when polled.

The DVIM will provide the driver with:

- Fault alerts – when it is detected that the RCVW system is not operating normally (e.g. VBS or RBS failure alerts.
- Inform alerts – to inform the driver when there is a potential need to stop at the HRI.
- Warnings – when the HRI is active and a rail crossing violation is imminent or when a violation is in progress

The type of warning issued to the roadway vehicle operator will be dependent on the Original Equipment Manufacturer (OEM) vehicle design decisions and human factors considerations. Multi-sensory alerts will be presented to the operator during impending violation scenarios.

VBS Validation Module

Maintenance vehicle VBS will include a VVM. The VVM is used to evaluate DSRC radio performance and the accuracy and repeatability of GPS derived positioning data.

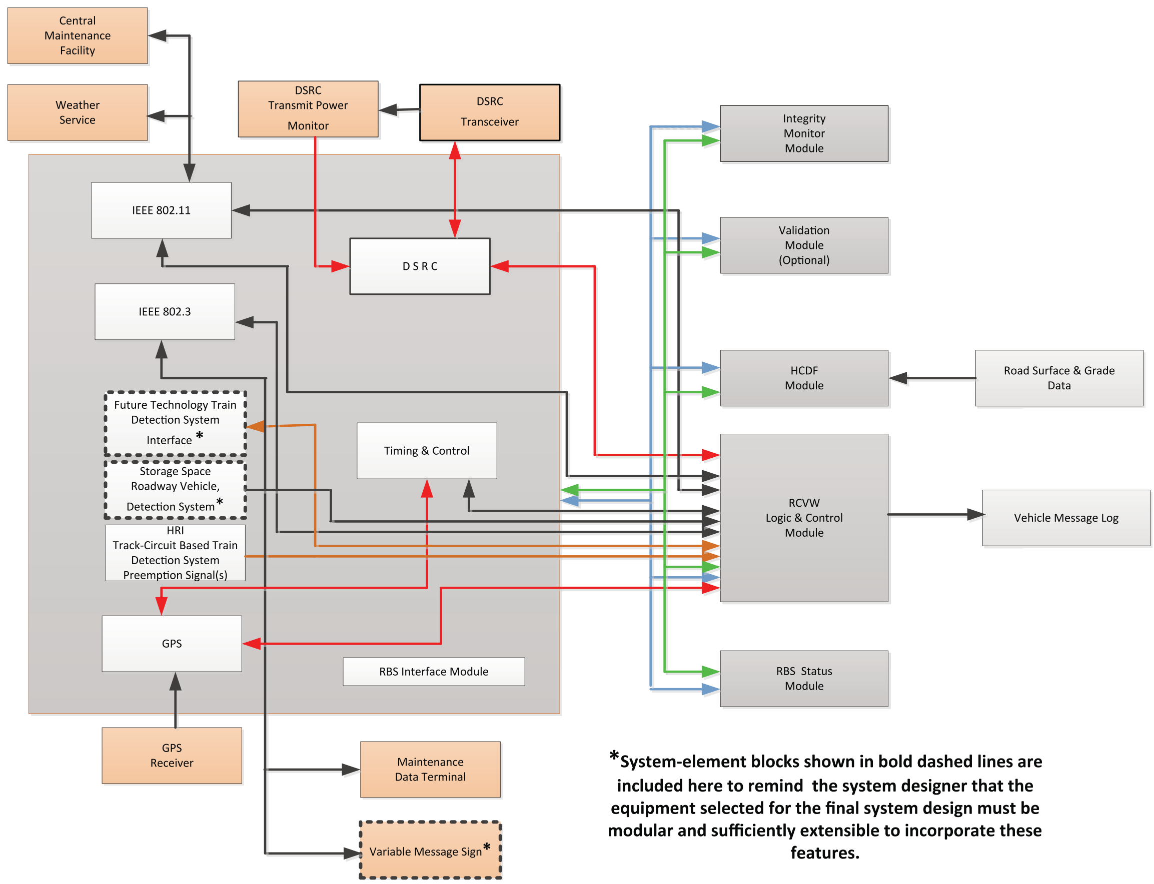
The VVM is required to baseline the HCDF and initial operational testing of the RBS. It will be used subsequently for periodic validation of RBS operation and HCDF data accuracy. This functionality may be provided by stand-alone components.

Note: *As noted above, Validation functionality has not been fully implemented in the RCVW Phase 2 prototype and may be implemented in future development.*

RBS

Figure 4-2 presents the adaptation of CICAS-V RBS to RCVW. The RBS shall be comprised of the following functional modules (and required supporting devices):

- Integrity Module
- RBS Interface Module (RIM) provides interfaces for:
  - RSU
  - Industry standard unlicensed-band wireless transceivers (IEEE 802.3 & IEEE 802.11)
  - Global Positioning System (GPS)
  - HRI track-circuit based controller
- RCVW Logic & Control Module (RLCM)
- HCDF Module
- RBS Status Module (RSM)
- RBS Validation Module (RVM)



Source: Final RCVW V2I SRS May 2016

Figure 4-2. Adaptation of CICAS-V RBS for RCVW

Note: *The RCVW Phase 2 prototype provides partial functionality for communications with a central maintenance facility. The collection of weather service information has been implemented, but as noted above is not being used by the RCVW Phase 2 prototype warning algorithm. As noted above, Validation Module functionality has not been implemented.*

RBS Integrity Module

The Integrity Module shall provide the monitor and control functions of the RBS. After initialization, the Integrity Module shall execute a BIST routine. Upon successfully completing the BIST routine, the Integrity Module shall initiate and monitor the subordinate RBS modules beginning with the RIM.

During Normal Operation Mode, the Integrity Module shall execute BIST routines once per second. The Integrity Module shall monitor each process and control routine in the system and shall shutdown or restart a routine when required. The Integrity Module shall perform its control function by periodically requesting status from each of the subordinate RBS modules. The modules shall respond with a status message that indicates either “normal function” or “error detected.”

Failure of a subordinate module to respond to a status request within 0.1 seconds shall be reported as an error.

If the Integrity Module detects errors in two consecutive requests from a module, the Integrity Module shall declare it as having “failed” and the RBS shall transition to Failure Mode.

While in Failure Mode, the Integrity Module shall attempt to restore the system. The first response of the Integrity Module shall be to shut down and restart the affected routine. If the first response fails to restore the system to normal operation, the next step shall be to reboot.

If rebooting fails to restore the system to normal operation, the RBS shall remain in Failure Mode. The Integrity Module shall report and record all software errors and hardware failures. The Integrity Module shall initiate the process to broadcast messages containing RBS status and HCDF revision level five times per second.

RIM

The RIM shall interface and manage communications with all external devices. Messages to be transmitted by the DSRC radio or a roadside network, as well as transactions with an MDT, shall be routed via the RIM.

- Specific to this SRS, the RIM shall provide the electrical and connector interfaces to process up to four HRI controller preemption signals (four trains approaching) from a single HRI.
- The RIM shall format messages that are to be transmitted by the DSRC radio to roadway vehicles in accordance with the IEEE 1609 suite of protocols.
- Messages sent to an MDT shall be formatted in accordance with the IEEE 802.3 standard.
- Messages sent via a roadside network shall be formatted and transmitted in accordance with industry standard wireless protocols.

The RIM shall receive data from the other RBS modules and devices, determine its destination, schedule the time of its broadcast, insert it into its designated space within the appropriate ITS standard message format, and dispatch it to the appropriate device.

Messages that are to be received by the RSU shall be in accordance with the suite of WAVE protocol standards. Messages transmitted by an MDT shall be formatted in accordance with the IEEE 802.3 standard.

The RSU WAVE messages broadcast to OBUs shall include the following types of information:

- RBS operational status and software revision level
- HCDF
- HRI status (active or inactive)

There are two types of messages that will be received by the RBS from a roadway or maintenance vehicle VBS:

- Validation related messages: While in Validation Mode, the RBS receives validation messages from maintenance vehicles.
- Vehicle warning status message: When the VBS DVI issues a warning to the driver, the message shall be sent to the RBS, where it will be time-stamped and archived for 48 hours.

Validation related messages and heartbeat messages shall be forwarded to the RVM.

The RIM design shall allow parameter changes for each of the RBS modules without the need to recompile the software. The RIM shall receive up-to-date configurable parameter settings for each module and store those settings for other modules to access. Upon request, the RIM shall send configuration data.

RBS RCVW Logic and Control Module

The RLCM shall process:

- Four HRI controller preemption signals (four trains approaching)
- Signals from two storage space roadway vehicle detection systems.

The RLCM shall be initialized by the Integrity Module. When the HRI status changes the RLCM shall initiate a change in status message directive. The directive shall be routed to the DSRC radio.

The RLCM shall initiate the HRI status message.

RBS HCDF Module

The HCDF Module stores the geometric HRI description data and sends the data to the VBS via the RIM and RSU when directed to do so.

The HCDF Module shall be initialized by the Integrity Module.

When an HRI configuration changes and the HCDF data is revised to reflect the change, its revision level shall be updated. When the HCDF revision level is changed, an HCDF advisory message shall be created and sent to the Integrity Module.

RBS Status Module

The RBS Status Module (RSM) shall be initialized by the Integrity Module. The RSM shall request status data from all modules having reportable status. The RSM shall also receive and store driver-warning messages that were issued to a driver by the DVI.

When a Vehicle Status Data request is received, the module shall retrieve the data, format a message, and send it.

RBS Validation Module (Required for Maintenance)

The RVM may be incorporated in:

- The RBS
- A system accessed via a roadside network
- The maintenance vehicle VBS

The RVM shall manage the RCVW testing that is conducted prior to the RBS being placed into service. Validation testing may also be performed as part of other scheduled maintenance activities. During validation testing, the RVM shall review the HCDF information, simulate inputs to the RLCM, monitor the messages that are sent to the maintenance vehicle VBS, and validate the required RSU signal reception area.

The RVM shall manage simultaneous data input and processing from two sources of HRI-related data. The RVM, after having been initialized by the Integrity Module shall perform the following tests:

- Coverage Mapping – The RVM shall evaluate the quality of the signal received from the maintenance vehicle OBU. The maintenance vehicle shall traverse all possible paths approaching and crossing the HRI. The RVM shall record the time when reception is acceptable and when it is not. The RVM shall correlate its time-stamped data with the time-stamped position data recorded by the maintenance vehicle VBS. This information shall be used to determine if the system is functioning as designed or needs to transition to Failure Mode.
- HRI Mapping – During its approach and crossing of the HRI, the maintenance vehicle shall acquire and record data. The RVM shall correlate the movement of the maintenance vehicle approaching and crossing the HRI with HRI reference points. The results shall be stored.
- Diagnostics and Logging – The RVM shall maintain a log of diagnostic messages created by RVM actions.

Upon request, the RVM shall retrieve validation data, format it into a message, and send it.

Note: *As noted above, Validation functionality has not been fully implemented in the RCVW Phase 2 prototype and may be implemented in future development.*

Chapter 5 Requirements Summary

RCVW

Table 5-1 provides RCVW specific requirements.

Table 5-1. RCVW requirements

Number	Requirement	ConOps Reference
RCVW-1	The system shall include a vehicle-based subsystem component and a roadside-based subsystem component.	N/A
RCVW-3	The system shall be modular and sufficiently extensible to address all design objectives defined in this SRS.	N/A
RCVW-5	The only point(s) of connection between the system and the train detection system shall be the preemption signal available through a track-circuit or IEEE 1570-compliant serial interface.	15
RCVW-7	The vehicle-based subsystem OBU and roadside-based subsystem RSU shall communicate in compliance with SAE J2735-2016, IEEE 1609, SAE J2739, and SAE J2450 (ITIS) Standards.	13
RCVW-8	All “over-the-road” licensed vehicles (i.e., vehicles of all vehicle classes) are included.	3
RCVW-11	The system shall be compliant with Connected Vehicle Personally Identifiable Information (PII) standards and guidelines.	N/A

Source: Battelle

VBS

Table 5-2 lists VBS requirements necessary for implementing RCVW.

Table 5-2. VBS requirements

Number	Requirement	ConOps Reference
VBS-1	The vehicle-based subsystem shall have the capability to produce alerts suitable for all licensed drivers.	1
VBS-2	The vehicle-based subsystem DVI shall have a human-machine interface (HMI) that is configurable to be audible, visual, both, or neither by the driver.	2
VBS-3a	The vehicle-based subsystem will present alerts that conform to In-Vehicle Display Icons and Other Information Elements, Volume 1: Guidelines and Human Factors Design Guidance for Driver-Vehicle Interfaces.	2
VBS-3b	The system shall provide two-stage alert messaging consisting of an informational, and, if applicable, a warning alert. *Note: An inform alert is non-obtrusive and serves to inform the driver of an active HRI ahead. This alert primes the vehicle operator for the potential need to stop at the HRI. A warn alert is obtrusive and occurs if it is predicted that the vehicle will not stop prior to the HRI using non-emergency braking. This alert serves to notify the vehicle operator that remains unaware of the active HRI ahead or who has decided to exercise poor judgement.*	1, 2
VBS-3c	The inform and warn alerts shall be multimodal in nature. *Note: Multimodal alerts may be visual, auditory or haptic.*	1, 2
VBS-4	The vehicle-based subsystem shall produce alerts that can be implemented in all vehicle classes and types equipped with appropriate connected vehicle technologies. *Note: vehicle-specific installation procedures may be required.*	3
VBS-5	The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters.	7
VBS-6	The vehicle-based subsystem shall process HRI configuration (GID) data that describes the geographic composition of the intersection.	8

Table 5-2. VBS requirements (Continued)

Number	Requirement	ConOps Reference
VBS-7	The vehicle-based subsystem shall be able to provide direction specific alerts. *Note: For clarity, the application shall be able to provide alerts to vehicles approaching the HRI and not alert vehicles departing the HRI.*	10
VBS-8	The system shall utilize a driver-vehicle interface (DVI) and, alternately, support display to OEM displays through standardized physical and electrical outputs.	
VBS-9a	The vehicle-based subsystem shall not interfere with any of the onboard safety systems, especially automotive industry automated safety systems	27
VBS -9b	The vehicle-based subsystem shall not interfere with any existing infrastructure subsystems (traffic control and HRI warning systems)	12a, 12b
VBS-10	The vehicle-based subsystem shall determine if the vehicle is within the HRI Hazard Zone and/or the HRI Approach Zone.	17
VBS-11a	The vehicle-based subsystem shall issue a unique warn alert that directs users to take evasive action to clear the HRI by any means when the vehicle is stopped within the HRI Hazard Zone. *Note: In the future, when SAE J2735 has been modified to support rail applications and the intersection zone (HRI Hazard Zone) or when an alternative approach is found to be viable, it is anticipated that the RCVW tool will be capable of distinguishing whether the crossing is active when the vehicle is within the HRI Hazard Zone. At that time, it is desired that this requirement will be transformed into two requirements – one for when the crossing is active where a warn alert such as the one described here is issued, and one when the crossing is not active where a new inform alert will instead be presented.*	17
VBS-11b	The vehicle-based subsystem shall issue warnings while the HRI is active when the vehicle is in the HRI Approach Zone if the vehicle is not decelerating sufficiently to stop safely before the HRI using non-emergency braking.	17
VBS-11c	The warning alert shall use a dynamic visual icon(s) and invasive auditory alert(s) in accordance with Campbell et al. (2016). Human Factors Design Guidance for Driver-Vehicle Interfaces.	1, 2
VBS-12	The vehicle-based subsystem shall issue an inform alert to the vehicle operator when the crossing ahead is active and rail crossing signage for an active crossing is within visual range according to the Guidelines for Advance Placement of Warning Signs in Table 2C-4 of the 2009 Manual on Uniform Traffic Control Devices (MUTCD), Revision 2, June 13, 2012.	5

Table 5-2. VBS requirements (Continued)

Number	Requirement	ConOps Reference
	Note: These guidelines identify where to place a warning sign (i.e. stop sign) in advance of a location with a potential stop condition according to the speed of the vehicle. The presentation of an Inform alert is limited to approaches toward active rail grade crossings to avoid nuisance alerting.	
VBS-13	The inform alert shall use static visual icons and non-invasive audible alert(s) in accordance with Campbell et al. (2016). Human Factors Design Guidance for Driver-Vehicle Interfaces.	5
VBS-14	The vehicle-based subsystem shall process the HRI status message in the context of its position with respect to the HRI, its instantaneous speed, acceleration, elevation of the approach with respect to the HRI, and possible other vehicle parameters to determine if an RCVW should be issued.	17
VBS-15	An RCVW warning shall be presented to the vehicle operator based on: 85th percentile driver response time, vehicle characteristics (i.e., vehicle class), and vehicle telematics (i.e. velocity, acceleration).	17
VBS-16	The vehicle-based subsystem shall not provide warnings when it is not inside the HRI Hazard Zone or HRI Approach Zone	17
VBS-17	Once issued, the graphical component of an inform alert will persist while the vehicle is within the approach zone, except when superseded by a warning or fault alert, or when the crossing becomes inactive.	17
VBS-18	The vehicle-based subsystem shall issue a fault alert to the vehicle operator when the RCVW system is not functioning in "normal" operations mode. A fault alert will be triggered when the VBS does not receive critical information, including: 1) position information (a) GNSS information being received at a rate lower than 10 hz (b) GNSS solution not providing an RTK fix, either floating or fixed-integer. 2) MAP (HCDF), 3) SPAT (which includes loss of the IEEE 1570 interface communication heartbeat from the HRI warning system, when this interface is used), or 4) DSRC communications (MAP and SPAT) when expected	20
VBS-19	Fault alerts shall supersede all other annunciations.	20

Table 5-2. VBS requirements (Continued)

Number	Requirement	ConOps Reference
VBS-20	Warn alerts shall supersede inform alerts.	N/A
VBS-22	The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms.	11
VBS-23	The vehicle-based subsystem shall be capable of processing received data within 85 ms.	26
VBS-24	The vehicle-based subsystem shall know the position of the GNSS antenna relative to the front of the vehicle and the rear of the vehicle.	7

Source: Battelle

RBS

Table 5-3 provides RBS requirements specific to this SRS.

Table 5-3. RBS requirements.

Number	Requirement	ConOps Reference
RBS-1	The roadside-based subsystem shall interoperate with current infrastructure safety systems (e.g. traffic control and Train Detection systems) in accordance with NEMA TS 2-2016 v03.07.	13
RBS-2	The roadside-based subsystem shall operate using 60 Hz 115VAC power as the primary power source.	12b
RBS-2b	The roadside-based subsystem shall determine HRI crossing status using preemption signal information from a voltage-based interconnection circuit or from an IEEE 1570-compliant serial interface.	12b
RBS-3	The infrastructure-based communication equipment shall be compliant with the V2I Hub Reference Implementation.	13
RBS-4	The roadside-based subsystem shall broadcast the HRI status message 10 times per second when an associated HRI controller activates a preemption signal.	15
RBS-5	The roadside-based subsystem shall stop broadcasting the HRI status message when the HRI controller deactivates the preemption signal(s).	15
RBS-7	The roadside-based subsystem shall broadcast the HRI MAP Data (HCDF) once per second.	13
RBS-10	The roadside-based subsystem shall execute periodic BIST, which includes a default mode that, if possible – depending on the nature of the failure, informs the driver via the vehicle-based subsystem when critical components are offline.	20
RBS-11	The roadside-based subsystem shall employ methods to prevent unauthorized physical and cyber access.	23
RBS-12	The V2I communication shall implement security as defined by IEEE 1609 Standards for Wireless Access in the Vehicular Environment (WAVE). For clarity, a unique security solution will not be developed for this project, but the available security solution provided by U.S. DOT for V2I communications will be exercised.	25

Table 5-3. RBS requirements. (Continued)

Number	Requirement	ConOps Reference
RBS-13	Secure-communication protocols shall not adversely impact the performance of the safety application with respect to the ability to provide alerts in a timely manner.	26
RBS-16	The roadside-based subsystem shall identify and log system failures to the extent that it is practicable.	21
RBS-18	The roadside-based subsystem shall incorporate self-recovering routines in order to recover from a major system failure associated with firmware/software systems.	21
RBS-20	The roadside-based subsystem shall not interfere with any HRI infrastructure subsystems.	12a
RBS-21	The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard.	12b
RBS-22	The roadside-based subsystem shall be capable of generating and broadcasting RTK corrections using the RTCM messaging protocol.	N/A

Source: Battelle

PUR

Table 5-4 provides PUR requirements specific to this SRS. The design of the prototype shall be sufficiently flexible and extensible so as to eventually incorporate the design related requirements in Table 5-4.

Table 5-4. Production unit requirements.

Number	Requirement	ConOps Stakeholder Needs Reference
PUR-1	Roadside-based subsystem functional modules shall report status within 0.2 seconds of a request by the roadside-based subsystem monitor. The roadside-based subsystem monitor shall transition the roadside-based subsystem to Failure Mode when two consecutive requests have not been acknowledged .	N/A
PUR-2	The roadside-based subsystem RSU DSRC radio transmitter/antenna shall provide mission-effective signal strength within the safe-stopping distance zones of an HRI.	9,11,14
PUR-3	The roadside-based subsystem, if possible, shall report to a central maintenance facility when the signal strength of its RSU DSRC Radio Frequency (RF) transmitter is less than its specified minimum.	14, 21
PUR-4	The BIST shall detect ≥ 95% of equipment related failures.	20, 21
PUR-5	The roadside-based subsystem false alarm rate shall not exceed 1%.	19a
PUR-6	The roadside-based subsystem failure to warn rate shall not exceed 1%.	19b
PUR-7	The equipment and system design shall include provisions to minimize the probability of wrong side failures.	19b
PUR-8	The validity of software routines shall be verified using stored test data once per second.	20, 21
PUR-9	Software modification shall require an Administrator Level password to prevent unauthorized modifications.	25
PUR-10	Future upgrades in vehicle-based subsystem software shall be compatible with existing roadside-based subsystem applications. Future upgrades in roadside-based subsystem applications will be compatible with vehicle-based subsystem applications.	28

Table 5-4. Production unit requirements. (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
PUR-11	The roadside-based subsystem shall report unauthorized access to the roadside-based subsystem shelter to a central maintenance facility via an industry standard wireless network.	24
PUR-12	The MTBF of the roadside-based subsystem shall not be less than 50,000 hours.	30
PUR-13	The MTTR of the roadside-based subsystem shall not exceed one hour.	30
PUR-14	The Availability of the roadside-based subsystem shall not be less than 0.9999, assuming a four hour mean time to restore service.	30
PUR-15	The roadside-based subsystem manufacturer shall commit to supporting the roadside-based subsystem functional components for a minimum of twenty years. Included in the support is providing replacement parts, or form, fit, and function equivalents.	32
PUR-16	The roadside-based subsystem manufacturer shall demonstrate that compliance with Configuration Management Plans is standard operating procedure.	33
PUR-17	The roadside-based subsystem manufacturer shall establish, unless already in existence, Reliability and Maintainability Improvement programs for the roadside-based subsystem.	33
PUR-18	The roadside-based subsystem RSU may, optionally, transition to a lower energy consuming state when no trains and no connected vehicles are present.	22
PUR-19	The roadside-based subsystem may, optionally, resume normal operations from a lower energy consuming state when trains or connected vehicles are present.	22
PUR-20	The roadside-based subsystem shall conduct self-diagnostic testing diagnosis and report status and/or failure to a centralized control center.	20, 21
PUR-21	Application and system logs (for example messages received from vehicle-based subsystem OBUs regarding roadside-based subsystem RSUs that failed to transmit Service Announcements) will be timestamped using an internally consistent mechanism (e.g., GPS or UTC time) and maintained until reported to a Central Maintenance Facility.	20, 21
PUR-22	All roadside-based subsystem components shall meet an operating temperature range of: -34ºC to 74ºC.	31

Table 5-4. Production unit requirements. (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
PUR-23	All roadside-based subsystem components shall meet a storage temperature range of: -45ºC to 85ºC.	31
PUR-24	All roadside-based subsystem components shall meet a relative humidity range of 95% condensing over the temperature range +4.4ºC to 43.3ºC.	31
PUR-25	Rain: Exposed components of the roadside-based subsystem, including the RSU, shall pass the rain test with a rainfall rate of 1.7 mm/min, wind speed of 18 m/sec and 30 minutes on each surface of the device as called out in MIL-STD-810 G method 506.5 Procedure 1.	31
PUR-26	Salt fog: Exposed components of the roadside-based subsystem, including the RSU, shall pass the salt fog test with 5% saline exposure for 2 cycles x 48 hours (24 hours wet/24 hours dry) as called out in MIL-STD-810 G method 509.5.	31
PUR-27	Wind: The roadside-based subsystem RSU mounting bracket shall be able to withstand winds up to 150 miles per hour per AASHTO Special Wind Regions Specification.B19.	31
PUR-28	Operating shock and vibration: The RSU shall comply with MIL-STD-810G, Methods 514.5C-17 and 516.5 Shock and Vibration. (Testing shall be conducted in accordance with the procedures specified in IEC-60068 and IEC-60721.)	31
PUR-29	Transportation shock and vibration (RBS components packaged for shipment): Roadside-based subsystem components shall comply with the United States Military Standard MIL-STD-810G, Test Method 514.6, Procedure I, Category 4. (Heavy truck profile) for packaging and shipping.)	31
PUR-30	Electromagnetic susceptibility: All roadside-based subsystem components shall be immune to Radio Frequency (RF) Electromagnetic Interference (EMI) per SAE J1113.	31
PUR-31	Electrostatic Discharge RSU: The roadside-based subsystem RSU shall be able to withstand electrostatic discharges from the air up to +/-15kiloVolts (kV) and electrostatic discharges on contact up to +/-8 kiloVolts (kV), in compliance with IEC EN61000-4-2.	31
PUR-32	Altitude: All roadside-based subsystem components shall remain operational from -60 to 3600 meters, referenced to sea level.	31

Source: Battelle

Performance

The RBS shall provide full functionality during all specified environmental and operating conditions in Chapter 3.

Interfaces

- The VBS and RBS shall include a DSRC wireless interface.
- The RCVW shall include the following protocol and connector interfaces:
  - DSRC wireless interface
  - IEEE 802.11 wireless via roadside network for communicating with central maintenance facility and weather service
  - Railroad industry standard connectors for HRI controller preemption input
  - IEEE 802.3 for an MDT.

Data and Data Structures

The RCVW application for the RBS shall conform to the data structures provided in Table 5-5 through Table 5-12. The tables are as presented in the CICAS-V SRS with references to highway intersections changed to HRI. Not all data elements are pertinent for the RCVW application.

The following tables represent the preliminary understanding of the data elements that are required for each data structure. The tables and data elements may require modification to meet the requirements of the final design. In this model, most of the data elements are defined by a standard. Whenever possible, the standard reference, standard data element name, and standard data type are used in the data element descriptions. For example, *NMEA:UTC_position_fix* indicates a data element defined in the NMEA-183 standard with the standard element name of *UTC_position_fix*.

Table 5-5. Data flow message sets.

Data Flow	ITS Message Standard	ITS Standard Message Set
RSU Data Request	To be determined	New Message Set Required
RSU Data Response	To be determined	New Message Set Required
RSU Data Update	To be determined	New Message Set Required
RSU Configuration Request	To be determined	New Message Set Required
RSU Configuration Response	To be determined	New Message Set Required
RSU Configuration Update	To be determined	New Message Set Required
Service Announcement	SAE J2735	New Message Set Required
HCDF(MAP)	SAE J2735	MSG_MapData
Area Geospatial Data	SAE J2735	MSG_MapFragment
Weather Data	SAE J2354	WeatherInformation
Coverage Validation Data	SAE J2735	MSG_ProbeVehicleData
Positioning Validation Data	SAE J2735	MSG_ProbeVehicleData
Geospatial Information Validation Data	SAE J2735	MSG_ProbeVehicleData
Positioning Correction	RTCM SC-104	SC-104_1005 SC-104_1074 SC-104_1084 SC-104_1094 SC-104_1124 SC-104_1230
The SAE standard defines the message wrapper for the Radio Technical Commission for Maritime Services (RTCM) message.	SAE J2735*	MSG_RTCMCorrections
Signal Data Request	To be determined	New Message Set Required
Signal Data Response	NTCIP 1202	TBD
Signal Phase and Timing Data	SAE J2735	MSG_SPAT
Driver Warning	ISO 11519-2:1994 ISO 11519-3:1994	TBD
Driver Notification	ISO 11519-2:1994 ISO 11519-3:1994	TBD
Vehicle Status Request	ISO 11519-2:1994 ISO 11519-3:1994	TBD

Data Flow	ITS Message Standard	ITS Standard Message Set
Vehicle Status Response	ISO 11519-2:1994 ISO 11519-3:1994	TBD
Vehicle Position Request	ISO 11519-2:1994 ISO 11519-3:1994	TBD
Vehicle Position Response	NMEA-183	RMC

Source: Final RCVW V2I SRS May 2016

Table 5-6. RBS configuration data.

RBS Configuration Data – Data Elements	Data Type
UT_Time_Stamp	Char: hhmmss.ss
UT_Date_Stamp	Char: ddmmyy
RSU_RCVW_Software_Version	Bin: 64 bit
HCDF_Content_Version	Int: 8 bit
HRI_ID	Int: 32 bit
Geospatial_Content_Version	Int: 8 bit
Geospatial_Dataset_ID	Int: 32 bit
RSU_Security_Certificate	TBD

Source: Final RCVW V2I SRS May 2016

Table 5-7. Positioning data.

Positioning Data – Data Elements	Data Type
UTC_position_fix (time)	Char: hhmmss.ss
Data_status (V=navigation receiver warning)	Char: A
Latitude of fix	Float: nnnn.nn
N or S	Char: A
Longitude of fix	Float: nnnnn.nn
E or W	Char: A
Speed over ground	Float: nnn.n
Track made good in degrees True	Float: nn.n
UT date	Char: ddmmyy

Positioning Data – Data Elements	Data Type
Magnetic variation degrees	Float: nn.n
E or W	Char: A

Source: Final RCVW V2I SRS May 2016

Table 5-8. Positioning correction data.

Positioning Correction Data – Data Elements	Data Type
Status	Bin: 16 bit
Week_Number	Int: 16 bit
Milliseconds_in_Week	Int: 32 bit
RTCM_1005_Message	Char: 19 bytes
RTCM_1074_Message	Char: Vary depend on number of satellites on view
RTCM_1084_Message	Char: Vary depend on number of satellites on view
RTCM_1094_Message	Char: Vary depend on number of satellites on view
RTCM_1124_Message	Char: Vary depend on number of satellites on view
RTCM_1230_Message	Char: Vary depend on number of satellites on view

Source: Final RCVW V2I SRS May 2016

Table 5-9. HRI geometric description data.

HCDF (Map) – Data Elements	Data Type
HRI_ID	Int: 32 bit
HCDF Data_Content_Version	Int: 8 bit
Reference_Point	Int: 8 bit
Reference_Point_ID	Int: 8 bit
Approach_ID	Int: 8 bit
HRI_Attributes	Bin: 8 bit
Latitude	Int: 32 bit (signed)
Longitude	Int: 32 bit (signed)

HCDF (Map) – Data Elements	Data Type
Altitude	Int: 16 bit (signed)
Road grade and surface parameters	Char: 252 byte limit
Lane_Number	Int: 8 bit
Lane_Width	Int: 16 bit
Lane_Attributes: percent grade and surface coefficient of friction	Bin: 16 bit

Source: Final RCVW V2I SRS May 2016

Table 5-10. Rail crossing violation warning.

Rail Crossing Violation Warning – Data Elements	Data Type
UT_Time_Stamp	Char: hhmmss.ss
UT_Date_Stamp	Char: ddmmyy
Warning Given	Int: 32 bit
HRI_ID	Int: 32 bit
Approach ID0	Int: 8 bit
Approach ID1	Int: 8 bit
Approach ID2	Int: 8 bit

Source: Final RCVW V2I SRS May 2016

Table 5-11. Vehicle error message.

Vehicle Error Message Data – Data Elements	Data Type
UT_Time_Stamp	Char: hhmmss.ss
UT_Date_Stamp	Char: ddmmyy
Error_Message_Type	Int: 32 bit
HRI_ID	Int: 32 bit
Approach_ID0	Int: 8 bit
Approach_ID1	Int: 8 bit
Approach_ID2	Int: 8 bit

Source: Final RCVW V2I SRS May 2016

Table 5-12. Weather data.

Weather Data – Data Elements	Data Type
UT_Time_Stamp	Char: hhmmss.ss
UT_Date_Stamp	Char: ddmmyy
HRI_ID	Int: 32 bit
NTCIP:EssAirTemperature (in tenths of degree C)	Int: (0…9999)
NTCIP:EssVisibility (in tenths of meters)	Int: (0…999999)
NTCIP:EssRoadwaySnowDepth (in centimeters)	Int: (0…999)
NTCIP:EssIceThickness (in millimeters)	Int: (0…999)
NTCIP:EssSurfaceBlackIceSignal (in millimeters)	Int: (0…99)
NTCIP:EssPrecipRate (tenths of grams per sq. meter per sec.)	Int: (0…99999)
NTCIP:EssMobileFriction	

Source: Final RCVW V2I SRS May 2016

Reliability Maintainability Availability

The RCVW RBS is comprised of a commercially available CICAS-V compliant RSU and a process-and-control device that interfaces with the RSU to accommodate inputs from the HRI controller.

Reliability

The Mean-Time-Between-Failures (MTBF) shall not be less than 50,000 hours.

Maintainability

To the extent feasible, the RBS shall be comprised of modules, with each module providing a specific function. The maintenance philosophy shall be isolate faults to a specific module – restore service by replacing it.

The Mean-Time-To-Repair (MTTR) shall not exceed one hour. MTTR includes time to isolate fault, replace module, and test.

Availability

The availability shall not be less than 0.9999 as calculated by:

A= MTBF/ (MTBF + MTTR + MRT); where MRT is the mean-time-to-respond, MRT is the mean intervening time between failure occurrence and the on-site arrival of repair personnel.

RBS Physical Security

The RBS shall be installed in a tamper and vandalism resistant housing per 49 CFR 236.3.

APPENDIX A. List of Acronyms

AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
BER	Bit Error Ratio
BIST	Built In Self-Test
BSM	Basic Safety Message
CEP	Circular Error Probability
CFR	Code of Federal Regulations
CICAS	Cooperative Intersection Collision Avoidance System
CICAS-V	Cooperative Intersection Collision Avoidance System for Violations
ConOps	Concept of Operations
DII	Driver Infrastructure Interface
DC	Direct Current
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
DVI	Driver Vehicle Interface
DVIM	Driver Vehicle Interface Module
EMI	Electromagnetic Interference
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
GHz	Gigahertz
GPS	Global Positioning System
HCDF	HRI Configuration Data File
HLCM	HRI Logic & Control Module
HRI	Highway Rail Intersection
Hz	Hertz
ID	Identification or Identifier
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
MDT	Maintenance Data Terminal
MIL-STD	Military Standard
MSRP	Manual of Standards and Recommended Practices
MTBF	Mean Time Between Failures
MTR	Mean Time to Respond
MTTR	Mean Time To Repair
NEMA	National Electrical Manufacturers Association
NHTSA	National Highway Traffic Safety Administration
NTCIP	National Transportation Communications for ITS Protocol
NTIA	National Telecommunications and Information Administration

OBU	On-Board Unit
OEM	Original Equipment Manufacturer
OSI	Open Systems Interconnection
OVM	OBU Validation Module
PTC	Positive Train Control
RCVW	Rail Crossing Violation Warning
RLCM	RCVW Logic and Control Module
RF	Radio Frequency
RIM	RSU Interface Module
RITA	Research and Innovative Technology Administration
RMS	Root Mean Square
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
RVM	RSU Validation Module
SAE	SAE International[6]
SAM	Situation Assessment Module
SIM	Systems Interface Module
SM	Status Module
SNR	Signal to Noise Ratio
SPaT	Signal Phase and Timing
TBD	To Be Determined
U.S. DOT	United States Department of Transportation
UT	Universal Time
USB	Universal Serial Bus
UTC	Coordinated Universal Time
VAC	Volts Alternating Current
VDC	Volts Direct Current
VM	Validation Module
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
WAVE	Wireless Access in Vehicular Environments
WCM	Wireless Communications Module

[6] Formerly known as Society of Automotive Engineers

APPENDIX B. Glossary of Terms

Dedicated Short Range Communications (DSRC): A short to medium range wireless protocol operating in the licensed 5.9 GHz band and specifically designed for automotive use. It provides communication between roadway vehicles and roadside infrastructure.

Driver Vehicle Interface: A visual and/or audible alert system

False Alarm: An indicated fault where no fault exists. A false negative is a situation when an HRI violation warning should have been issued, but was not. A false positive is a situation where an HRI violation warning was unnecessarily issued.

Geospatial Database: A database with geospatial information about HRIs. The database contains information such as the HRI IDs for all RCVW HRI within a defined area.

Global Positioning System (GPS): A satellite-based navigational system allowing the determination of a unique point on the earth's surface with a high degree of accuracy. The network of satellites is owned by the US Department of Defense. It uses a satellite constellation of at least 24 satellites.

HRI Geometric Description: A digital representation of the geometry of the HRI that enables the roadway vehicle to correlate its position with respect to the HRI.

On-Board Unit: A unit in a vehicle that includes a WAVE radio and the software to operate the radio.

Roadside-Based Subsystem: A Roadside Unit (RSU) and an Integrated Vehicle-to-Infrastructure Prototype computing platform.

Roadside Unit: A unit at the roadside that includes a WAVE radio and the software to operate the radio.

Stop Line: Demarcated location on an approach to an HRI where roadway vehicles are required to stop when stipulated by statute or RCVW warning. The stop line location will be included in the geometric HRI description. For HRI approaches that do not have a stop line, an appropriate stopping location will be included in the geometric HRI description.

Vehicle-Based Subsystem: An On-Board Unit (OBU), Integrated Vehicle-to-Infrastructure Prototype computing platform, and Driver Vehicle Interface (i.e., visual and/or audible alert system)

Vehicle-to-Vehicle Communication: Communication between vehicles using 5.9 GHz DSRC WAVE radios.

Violation: A violation condition may be detected or predicted by the RCVW when the HRI protection system is active due to a train being present or approaching. Detected violation warnings are issued when the vehicle driver is not taking appropriate action to stop the vehicle within the HRI Approach Zone.

Wireless Access in Vehicular Environments (WAVE): WAVE standards (A suite of IEEE 1609 standards) provide the radio communication component that supports the U.S. Department of Transportation's Vehicle-Infrastructure Initiative and Intelligent Transportation System program. See DSRC WAVE standards that support V2V and V2I communications.

APPENDIX C. DSRC Potential Restriction Zones

Operation of a RSU within 75 kilometers of the GPS coordinates listed below must be approved by the National Telecommunications and Information Administration (NTIA).

Location	Latitude	Longitude
Ft. Lewis, WA	470525N	1223510W
Yakima Firing Center, WA	464018N	1202135W
Ft. Carson, CO	383810N	1044750W
Ft. Riley, KS	385813N	0965139W
Ft. Shafter, HI	211800N	1574900W
Hunter Army Airfield, GA	320100N	0810800W
Ft. Gillem, GA	333600N	0841900W
Ft. Benning, GA	322130N	0845815W
Ft. Stewart, GA	315145N	0813655W
Ft. Rucker, AL	311947N	0854255W
Yuma Proving Grounds, AZ	330114N	1141855W
Ft. Hood, TX	310830N	0974550W
Ft. Knox, KY	375350N	0855655W
Ft. Bragg, NC	350805N	0790035W
Ft. Campbell, KY	363950N	0872820W
Ft. Polk, LA	310343N	0931226W
Ft. Leonard Wood, MO	374430N	0920737W
Ft. Irwin, CA	351536N	1164102W
Ft. Sill, OK	344024N	0982352W
Ft. Bliss, TX	314850N	1062533W
Ft. Leavenworth, KS	392115N	0945500W
Ft. Drum, NY	440115N	0754844W
Ft. Gordon, GA	332510N	0820910W
Ft. McCoy, WI	440636N	0904127W
Ft. Dix, NJ	400025N	0743713W
Parks Reserve Forces Training Area, CA	374254N	1214218W
Ft. Hunter Ligget, CA	355756N	1211404W
Pacific Missile Test Center, CA	340914N	1190524W
Naval Air Development Center, PA	401200N	0750500W
Mid-Atlantic Area Frequency Coordinator, MD	381710N	0762500W
Naval Research Laboratory, MD	383927N	0763143W
Naval Ocean Systems Center, CA	324500N	1171000W
Naval Research Laboratory, DC	385500N	0770000W
Naval Surface Weapons Center, MD	390205N	0765900W
Naval Electronic Systems Engineering Activity, MD	381000N	0762300W
Midway Research Center, VA	382640N	0772650W
Aberdeen Proving Ground, MD	392825N	0760655W
Ft. Huachuca, AZ	313500N	1102000W
Ft. Monmouth, NJ	401900N	0740215W
Picatinny Arsenal, NJ	405600N	0743400W
Redstone Arsenal, AL	343630N	0863610W
White Sands Missile Range, NM	322246N	1062813W
Army Research Laboratory, MD	390000N	0765800W
Space and Missile Systems Center, CA	335500N	1182200W

Location	Latitude	Longitude
Edwards AFB, CA	345400N	1175200W
Patrick AFB, FL	281331N	0803607W
Eglin AFB, FL	302900N	0863200W
Holloman AFB, NM	322510N	1060601W
Kirtland AFB, NM	350230N	1063624W
Griffiss AFB, NY	431315N	0752431W
Wright-Patterson AFB, OH	394656N	0840539W
Hanscom AFB, MA	422816N	0711725W
Nellis AFB, NV	361410N	1150245W
Vandenberg AFB, CA	344348N	1203436W
U.S. Air Force Academy, CO	385800N	1044900W
Brooks AFB, TX	292000N	0982600W
Arnold AFB, TN	352250N	0860202W
Tyndall AFB, FL	300412N	0853436W
Charles E. Kelly Support Facility—Oakdale, PA	402357N	0800925W

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