Rail Crossing Violation Warning

System Requirements Specification

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14. ABSTRACT (Maximum 200 words)

The Rail Crossing Violation Warning (RCVW) application provides the means for equipped connected vehicles (CV) on approach to a highway-rail intersection (HRI) to be warned of an imminent violation of an HRI active warning/protective system through the interconnection of a CV Roadside-Based Subsystem (RBS) with track-circuit based train detection systems in place at active HRIs. The system includes a Cloud-based Subsystem (CBS) which broadcasts HRI information such as train presence to subscribers.

This System Requirements Specifications (SRS) document describes the operational requirements Vehicle-to-Everything (V2X) Rail Crossing Violation Warning (RCVW).

This document supersedes and replaces the RCVW SRS document created under FRA contract number 693JJ6-18C-000019

15. SUBJECT TERMS
Rail Crossing Violation Warning, RCVW, connected vehicles, CV, CAV, Highway-Rail Intersection, signal phase and timing, SPaT, Map Data, MAP, Institute of Electrical and Electronics Engineers, IEEE, C-V2X, Cloud-Based

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1 quart (qt) = 0.96 liter (l)	
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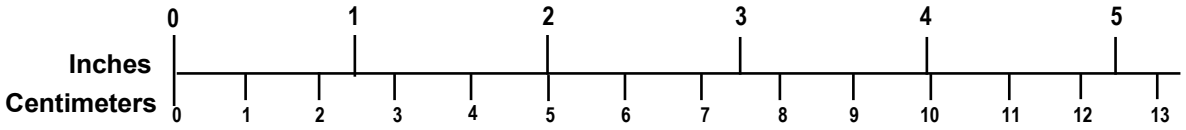

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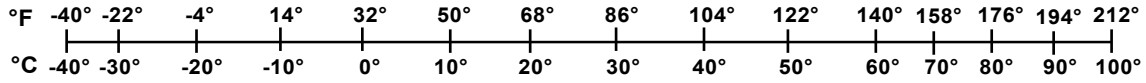

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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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
E	1/31/2023	Addition of requirements for a cloud-based Subsystem Addition of C-V2X related requirements Updates to Standards General Edits	Various
F	05/05/2023	Addressed comments from FRA/VOLPE	Various
G	07/18/2023	Addressed comments from FRA/VOLPE Updated Requirements	Various

Executive Summary

This System Requirements Specifications (SRS) document describes the operational requirements for a Vehicle-to-Everything (V2X) Rail Crossing Violation Warning (RCVW) Connected Vehicle (CV) safety application enhanced with a cloud-based messaging module.

The CV 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. The application is enhanced with a cloud-based message module which provides notifications to cloud subscribed users on the status of the HRI's protective warning device (active or not active). This information can be used by traffic management centers (TMC), first responders, commercial vehicle dispatchers, vehicle navigation applications and any entity that could benefit in knowing real time status of an HRI.

This document presents the requirements for an HRI connected vehicle safety application that is based on CV and complemented with cloud-computing concepts. The requirements incorporate/integrate a cloud-based component into the RCVW roadside-based component 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 protective warning device 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 CV safety application are **safety, mobility,** and **environmental** related. The safety-related improvement is a reduction in the frequency and severity of HRI incidents.

Chapter 1 Introduction

In an effort to increase the safety, mobility, and awareness to motorist interaction with a Highway-Rail Intersection (HRI), the Federal Railroad Administration (FRA) commenced a project to develop a Rail Crossing Violation Warning (RCVW) Concept of Operations (ConOps). This ConOps integrates Connected Vehicle (CV) concepts and cloud computing capabilities at 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
- Scenarios illustrative of the HRI configurations and functions.

Chapter 2 summarizes the documentation referenced throughout the SRS. This includes: Code of Federal Regulations (CFR), United States Department of Transportation (US DOT), Institute of Electrical and Electronics Engineers (IEEE), National Electrical Manufacturers (NEMA), SAE International (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 three RCVW subsystems:

RCVW CV Roadside-Based Subsystem (RBS)

1. Roadside Unit (RSU) (i.e., C-V2X[1] radio in an RBS)
2. V2X Hub computing platform running the RCVW roadside application

RCVW CV Vehicle-Based Subsystem (VBS)

1. On-Board Unit (OBU) (i.e., C-V2X radio in a VBS)
2. Vehicle to Everything (V2X) Hub computing platform running the RCVW in-vehicle application
3. Driver Vehicle Interface (DVI) (i.e., display and/or audible alert system)

RCVW Cloud-Based Subsystem (CBS)

1. Messaging as a Service (MaaS) platform
2. Cloud database platform
3. Serverless architecture

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

[1] C-V2X:Connected Vehicle to Everything

Chapter 5 provides a tabular summary of the RCVW system level, RBS, VBS and CBS requirements. It additionally includes production unit requirements (PUR), which will be addressed once the system is ready for production.

System Purpose

The RCVW concept includes CV and cloud-based technology to enhance awareness at HRIs equipped with active protective warning device (bells flashing lights and/or gates). CV technology is the core of the RCVW vehicle safety application which provides warnings and alerts to RCVW VBS-equipped-vehicle drivers as they approach an RCVW RBS equipped HRI. The CBS serves the specific function of relaying real-time HRI information to authorized subscribed users.

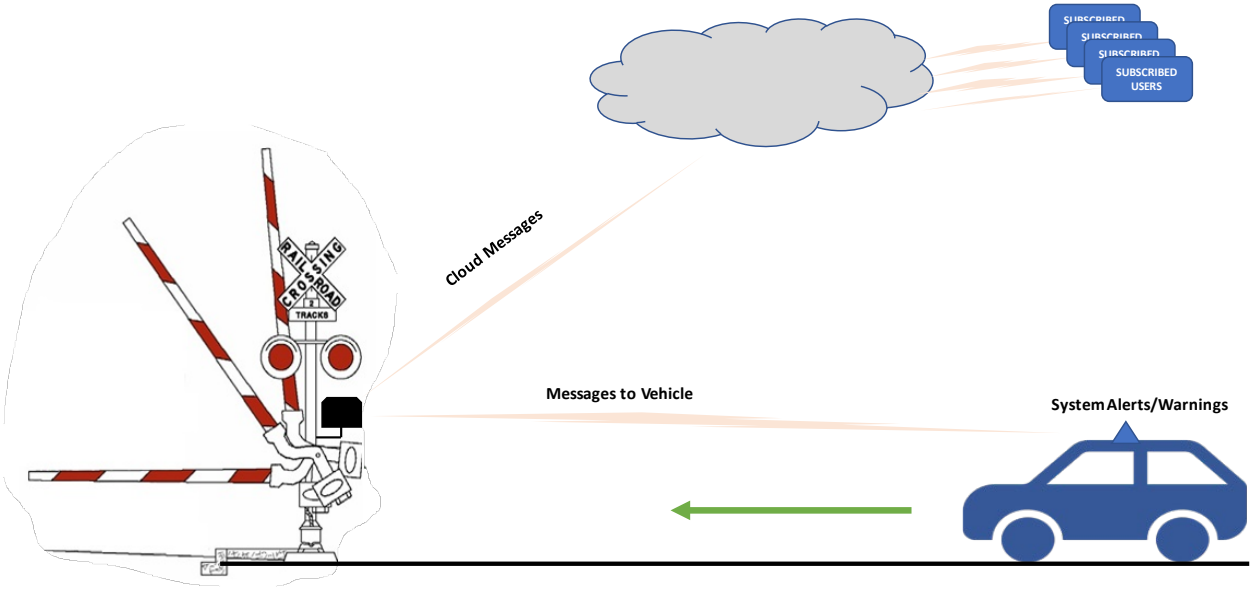

Figure 1. Basic Concept of RCVW at an HRI with RBS

In Figure 1, information is being broadcasted in two separate ways:

1. To authorized subscribed users via the cloud subsystem using an internet connection.
2. To any CV in range over radio.

Both the CV approaching the HRI and cloud subscribers receive the following information:

1. HRI Identification (ID) and RBS operational status
2. HRI Status (warning devices activated or deactivated)
3. HRI Configuration

In addition, the CV VBS receives the Radio Technical Commission for Maritime Services (RTCM) corrections

The following are the main functions of the system:

1. When a CV equipped with an RCVW VBS system is approaching an RCVW enabled active HRI (i.e., an HRI for which the protective warning device are activated):

- The VBS will produce an informational alert indicating that the protective warning device are activated.
- The VBS will produce a warning alert if it predicts the driver is not taking sufficient action to prevent a violation (collision with the protective warning device or vehicle not able to stop prior to entering the crossing).
- The VBS will produce a fault alert if:
    - the OBU is not receiving a radio broadcast from the RBS being approached or if the rate of data reception is lower than what is required (See RCVW System Context for more details).
    - the accuracy of the Global Navigation Satellite System (GNSS) position is below what is required (See RCVW System Context for more details).

2. When a CV equipped with an RCVW VBS enters an HRI equipped with an RCVW RBS and remains within the hazard zone (15 feet from the nearest rail of the track), the VBS system will issue a specific warning depending on the status of the protective warning device:

    - If protective warning device are not active, it will warn the driver to clear the tracks.
    - If protective warning device are active, it will warn the driver to clear the tracks and indicate that the protective warning device are activated.

3. The RBS will broadcast to the CBS the following information:

    - HRI ID
    - HRI's protective warning device status (activated or not activated)
    - HRI Geometry
    - RBS Diagnostics

4. The CBS subsystem will provide a data interface that will allow authorized subscribers to receive real time information received from the RBS.
5. The CBS shall relay RTCM messages to the RBS to be broadcast to the VBS for GNSS positional corrections

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
- Provide real time HRI activation Status information to authorized subscribers via the internet.

Definitions

The following HRI configurations were considered in developing scenarios for the RCWV CV safety application:

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

The current design of the RCVW CV safety application supports only the configuration presented in Figure 2. However, the RBS and by extension the CBS is able to broadcast information of all the listed HRI configurations. The RCVW CV safety application can be adapted for other HRI configurations in future development.

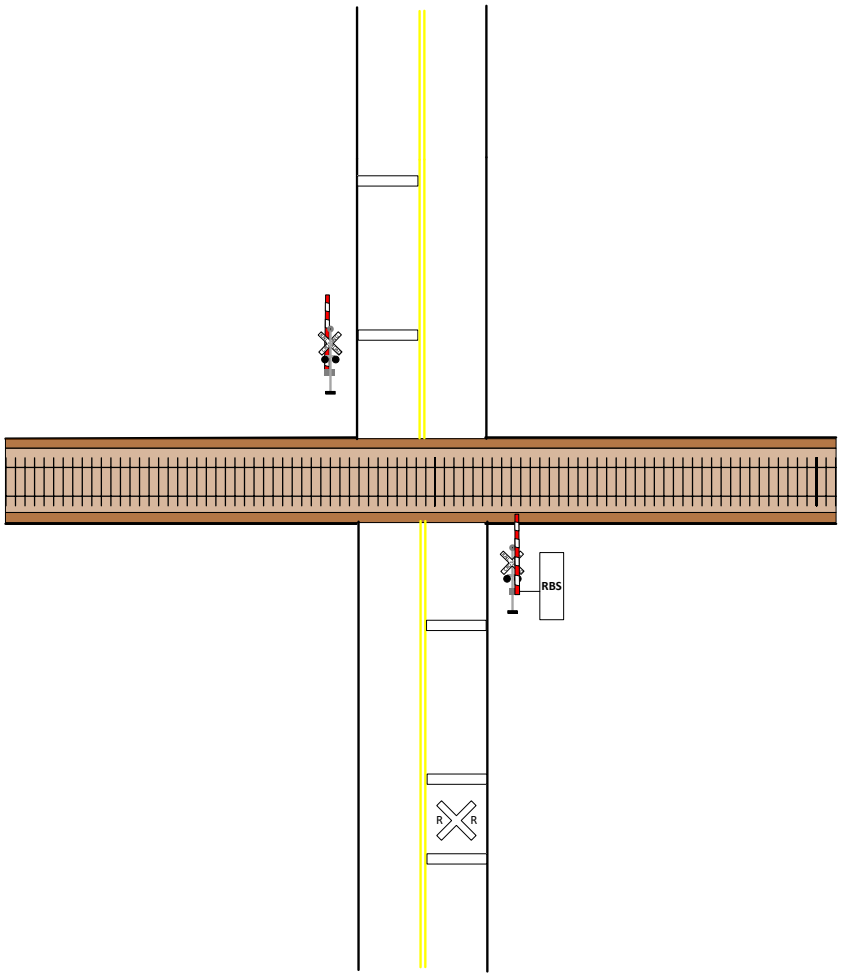

Figure 2.HRI with no nearby roadway intersection.

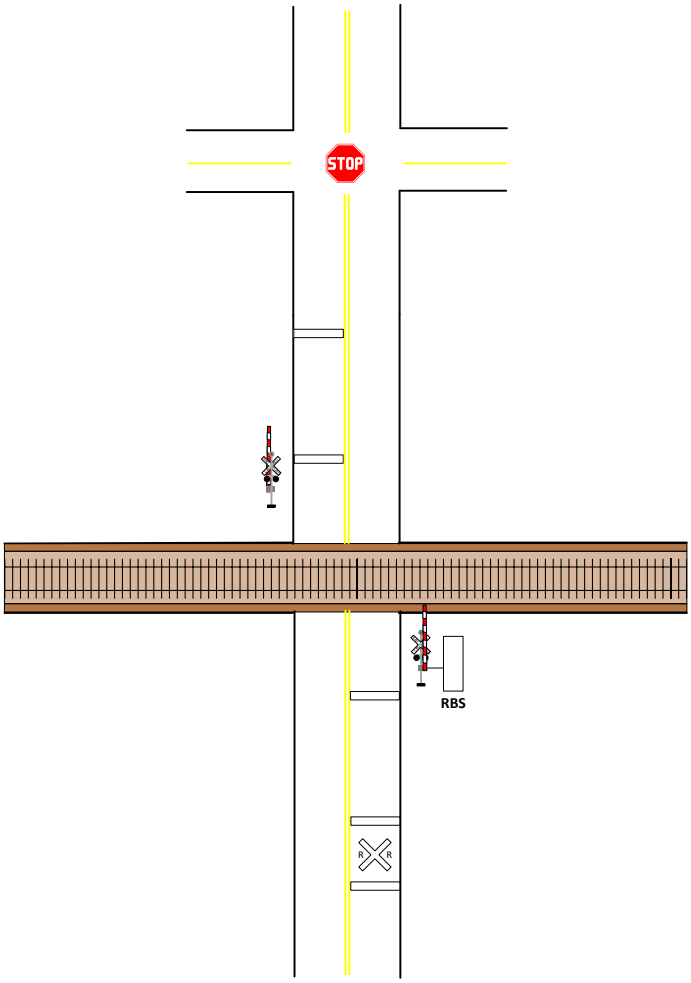

Figure 3. HRI with nearby roadway intersection.

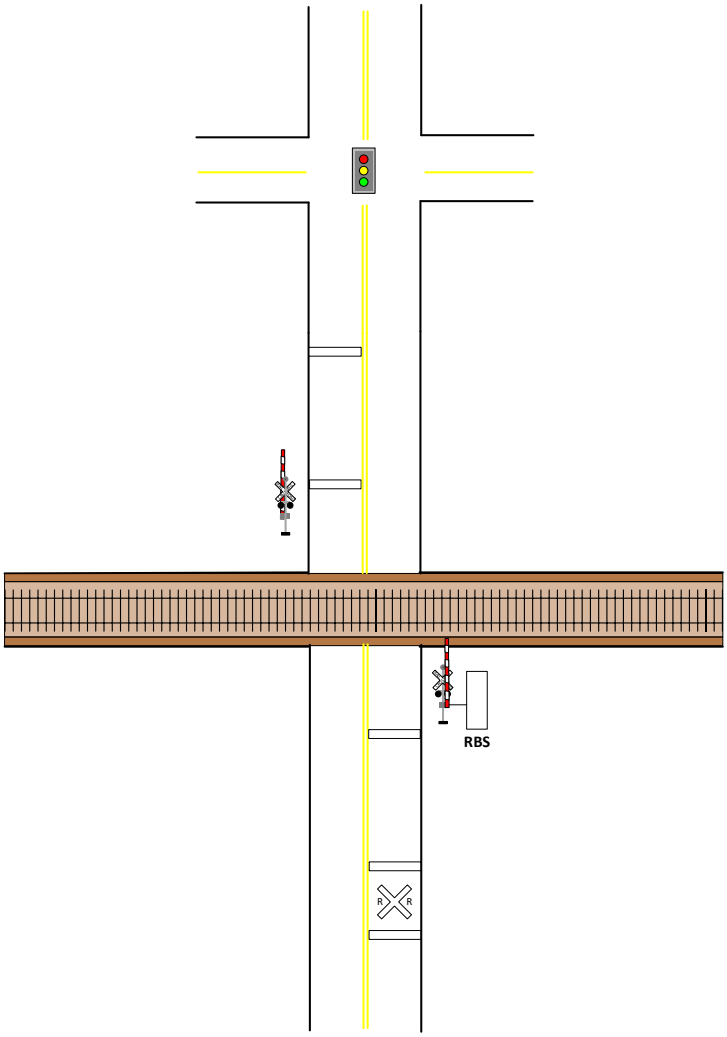

Figure 4. HRI with nearby signalized roadway intersection.

For the RCVW system, the HRI is composed of two distinct zones, the Hazard Zone, and the Approach Zone:

- HRI Hazard Zone: The HRI Hazard Zone is the roadway between the stop bars on either side of the railroad track and covering all lanes within, this is done to detect vehicles that leave their approach lane attempting to circumnavigate the gates. This is shown in red in Figure 5.
- HRI Approach Zone: The HRI Approach Zone is the zone within which the VBS may issue in-vehicle warnings. Imminent collision warnings within this zone will be determined by an algorithm executed by the VBS that will consider factors including vehicle speed, typical reaction time of an operator, approaching road grade, vehicle deceleration rate, assumed worst case positional inaccuracies, communication, and processing latencies. The HRI Approach Zone is in yellow in Figure 5.

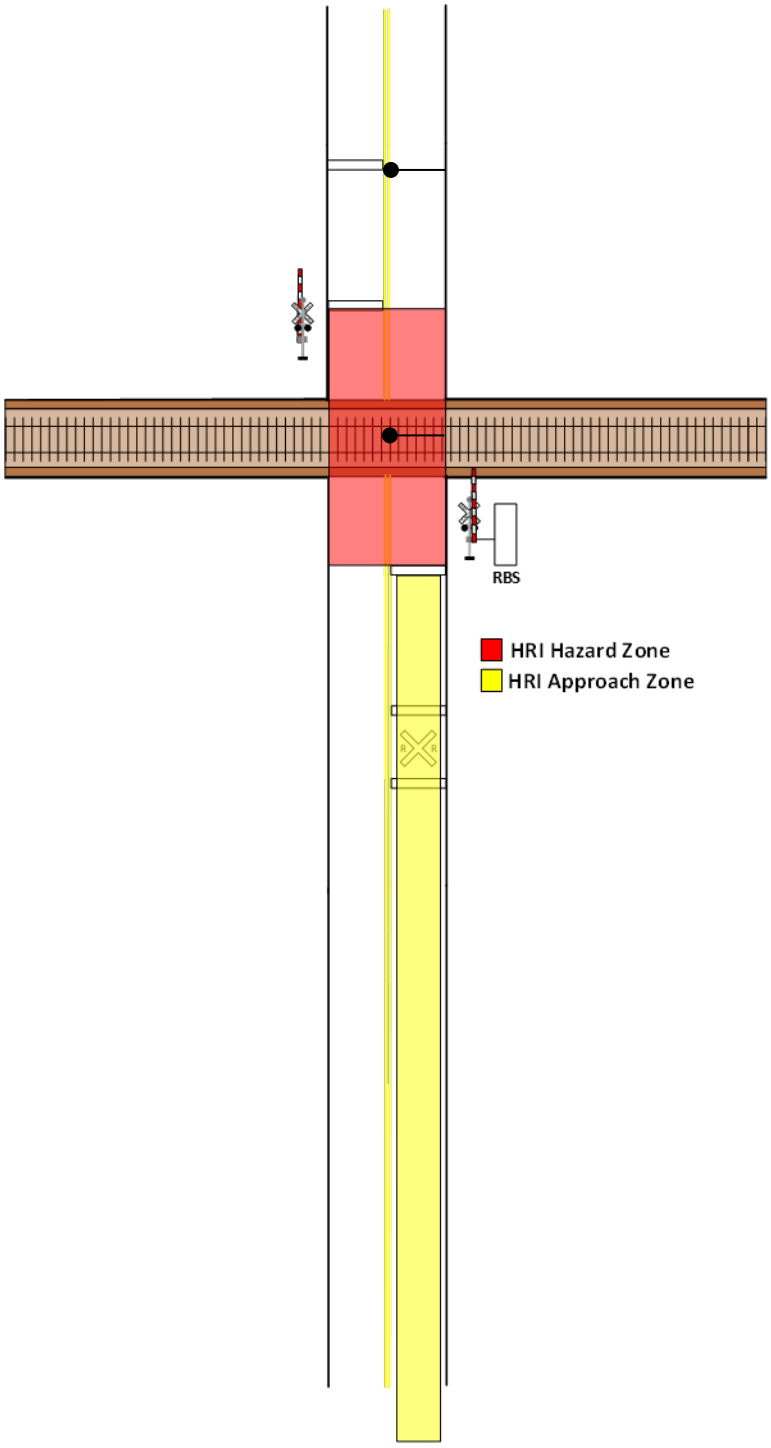

Figure 5. HRI Zones

Note that the approach 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 RCWV CV safety application produces three types of warnings:

1. RCVW: When the HRI protection system is active and the RCVW application determines that the driver is not taking appropriate action to stop the vehicle, the VBS produces an RCVW Warning message designed to produce a visual and audible alert. This warning type is represented by the situation depicted in Figure 6.
2. Clear HRI Warning (protective warning device deactivated): When the vehicle is within the HRI Hazard Zone, the protective warning device are deactivated and the vehicle operator is not taking action to clear the HRI Hazard Zone, the DVI displays a Clear HRI Warning designed to produce a visual and audible warning to the driver – This warning type is represented by the situation depicted in Figure 7.
3. Clear HRI Warning (protective warning device activated): When the vehicle is within the HRI Hazard Zone, the protective warning device are activated and the vehicle operator is not taking action to clear the HRI Hazard Zone, the DVI displays a Clear HRI Warning message designed to produce a visual and audible warning to the driver (the visual message adds icons indicating a vehicle breaking the gate) –This warning type is represented by the situation depicted in Figure 8.

The VBS will only produce alerts and warnings when the vehicle is within the HRI Approach zone and/or the HRI Hazard zone. Outside of these two zones the system is not active.

Note that figures are illustrative examples and not drawn to scale.

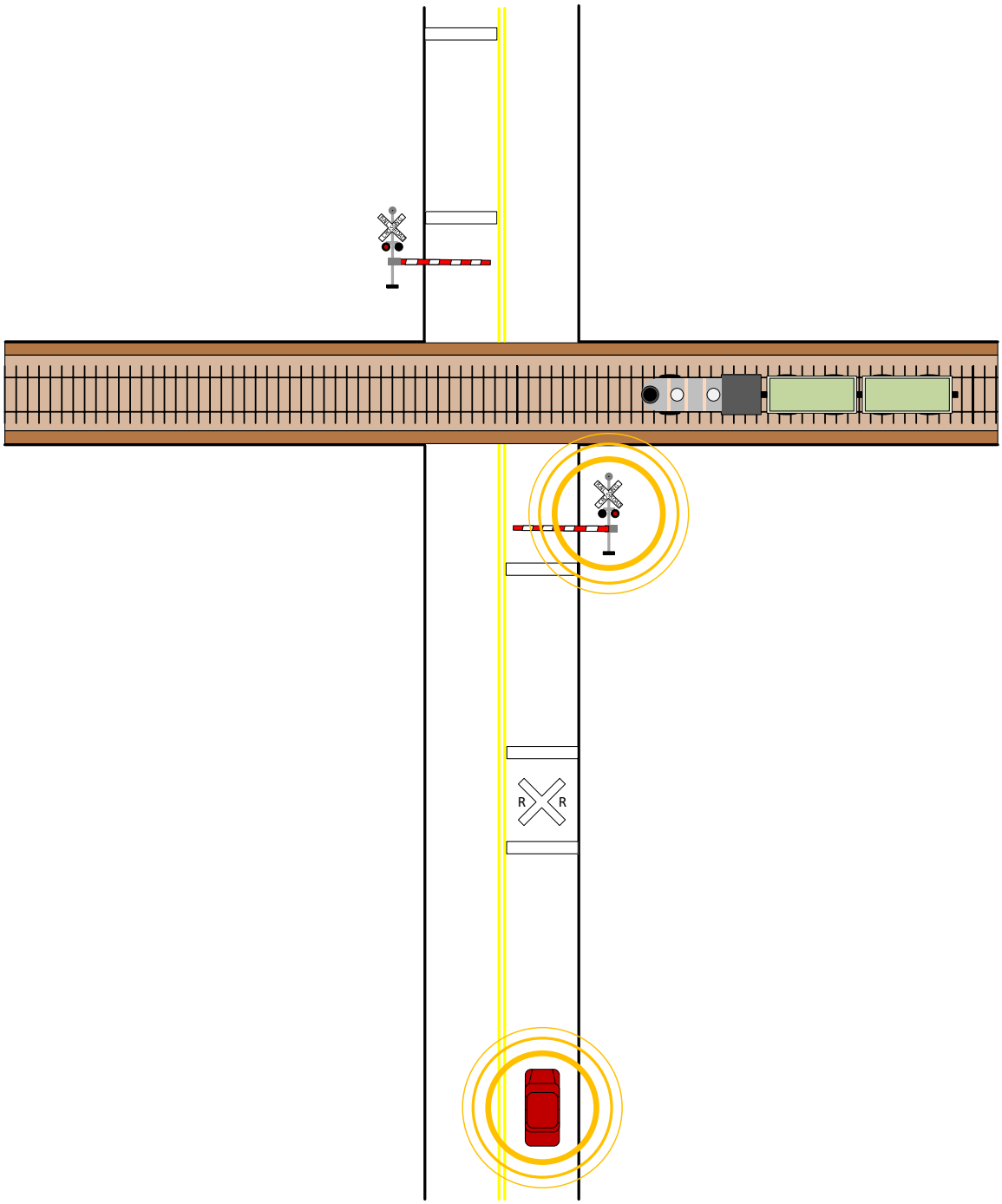

Figure 6. Rail Crossing Violation Warning

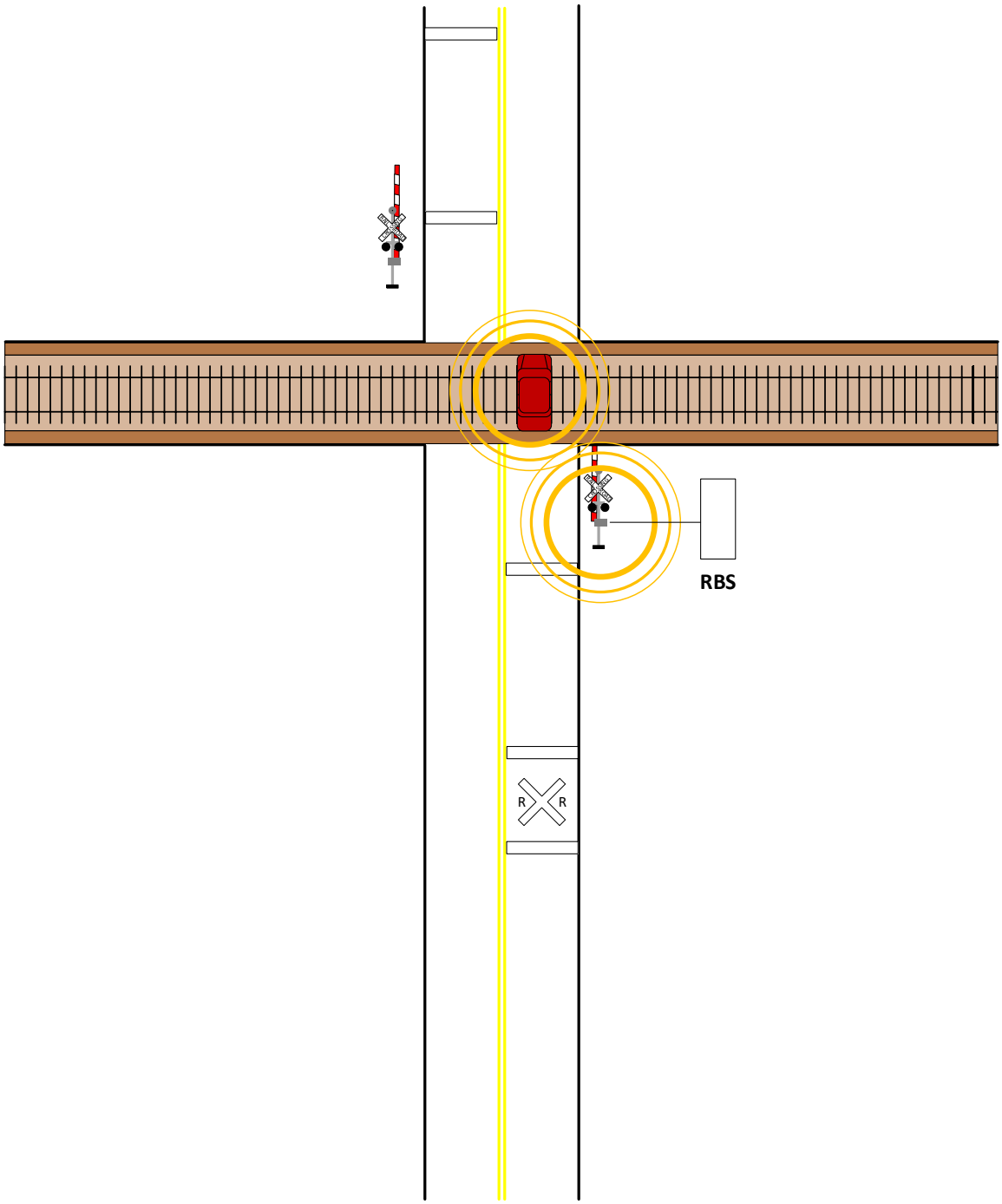

Figure 7. Clear HRI Warning

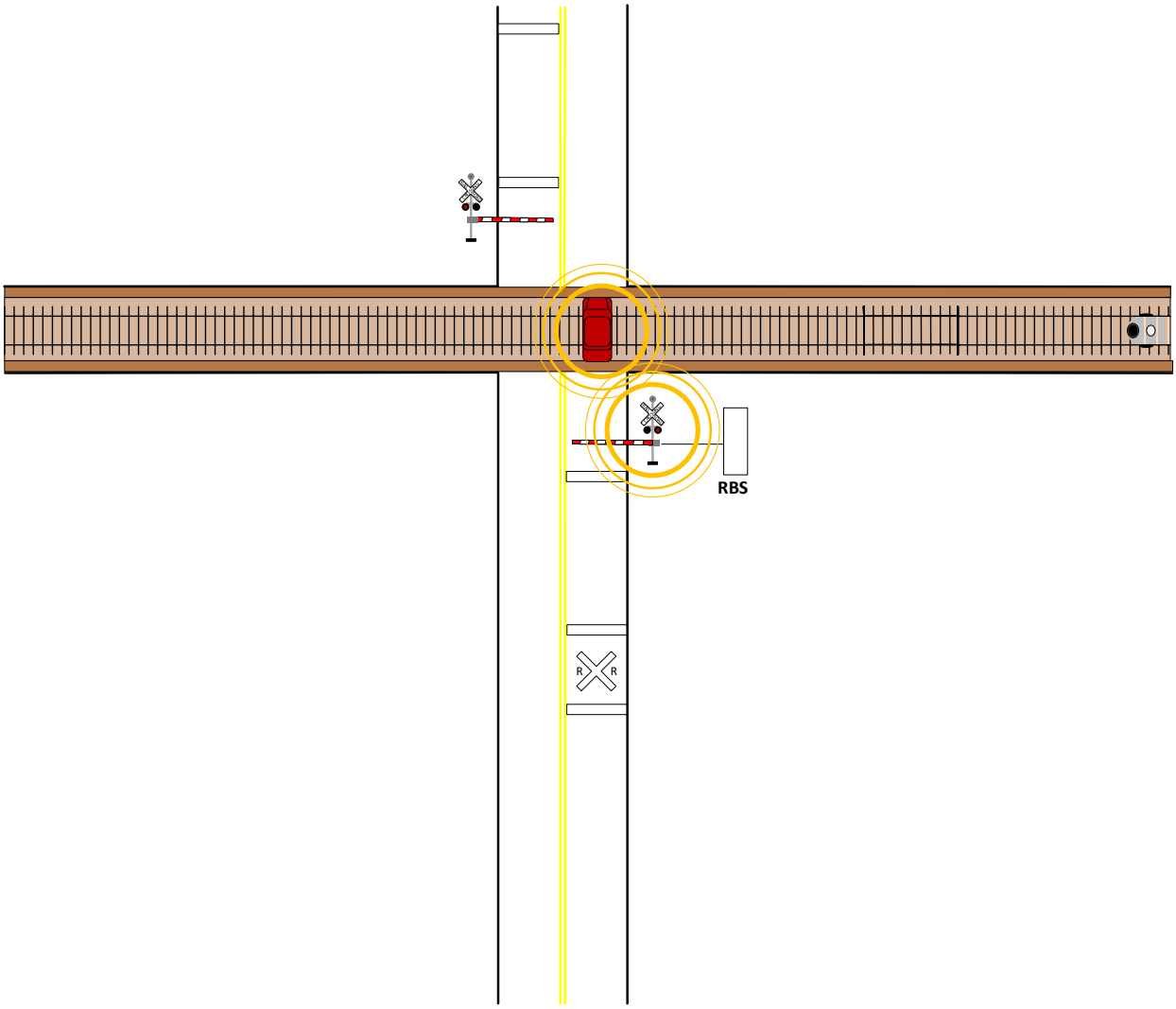

Figure 8. Clear HRI Warning - Protective warning device Activated

In addition to the vehicle RCWV CV safety application, the system architecture includes a CBS. This subsystem's main function is to provide pre-approved and authorized subscribers the current operational and activation status of RBS equipped HRIs. The CBS keeps a database of known HRI's along with information related to the crossing such as

- Unique ID
- Geographical location
- Geometry
- Low ground clearance
- Active or passive
- RCVW RBS equipped.

The CBS is able to receive, store and broadcast to subscribers the current activation status of an HRI as well as its RBS's diagnostics. The CBS is also designed to connect to Continuously Operating Reference Station (CORS) networks to retrieve RTCM corrections which can then be forwarded via the internet to specific RBSs for processing and broadcast to approaching RCVW VBS equipped vehicles.

The current design of the CBS only supports the dissemination of HRI activation status information to subscribed users via a third party. It is not currently intended to provide an alternate means for the VBS to receive HRI activation status . The CBS may be adapted for the communication of the necessary messages to enable a vehicle safety application in future development.

CV Safety Application Scenarios

The following scenarios shall be addressed by the RCVW CV safety application algorithm. The following scenarios are illustrative of the HRI configurations that shall be considered. The scenarios depict variations of vehicle position relative to the HRI Hazard Zone and HRI Approach Zone. 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.

CV Scenario 1: Vehicle Approaches an Equipped HRI; HRI Protection System is Not Active

1. There is no train approaching or occupying the HRI; protective warning device have not been activated.
2. The VBS DVI displays a fault alert if it fails to receive a broadcast from a "known" RBS.
3. No alerts or warnings are issued.

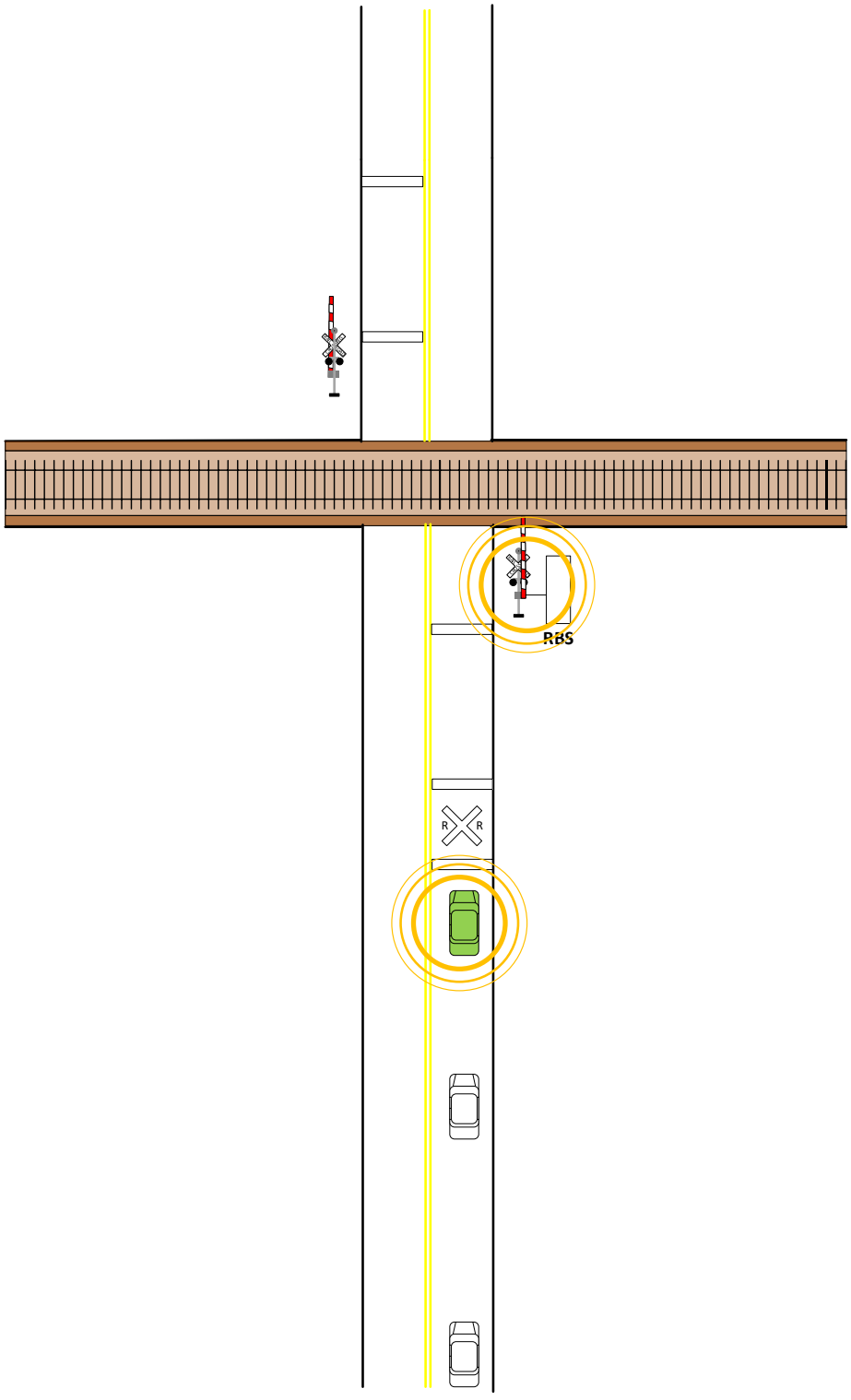

Figure 9. CV Scenario 1

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

1. A CV enters an HRI Approach Zone.
2. A train is approaching or occupying the HRI; protective warning device have been activated
3. The DVI provides an inform alert.
4. If the driver does not react appropriately to prevent a predicted RCVW, an emphatic warning shall be displayed by the DVI.

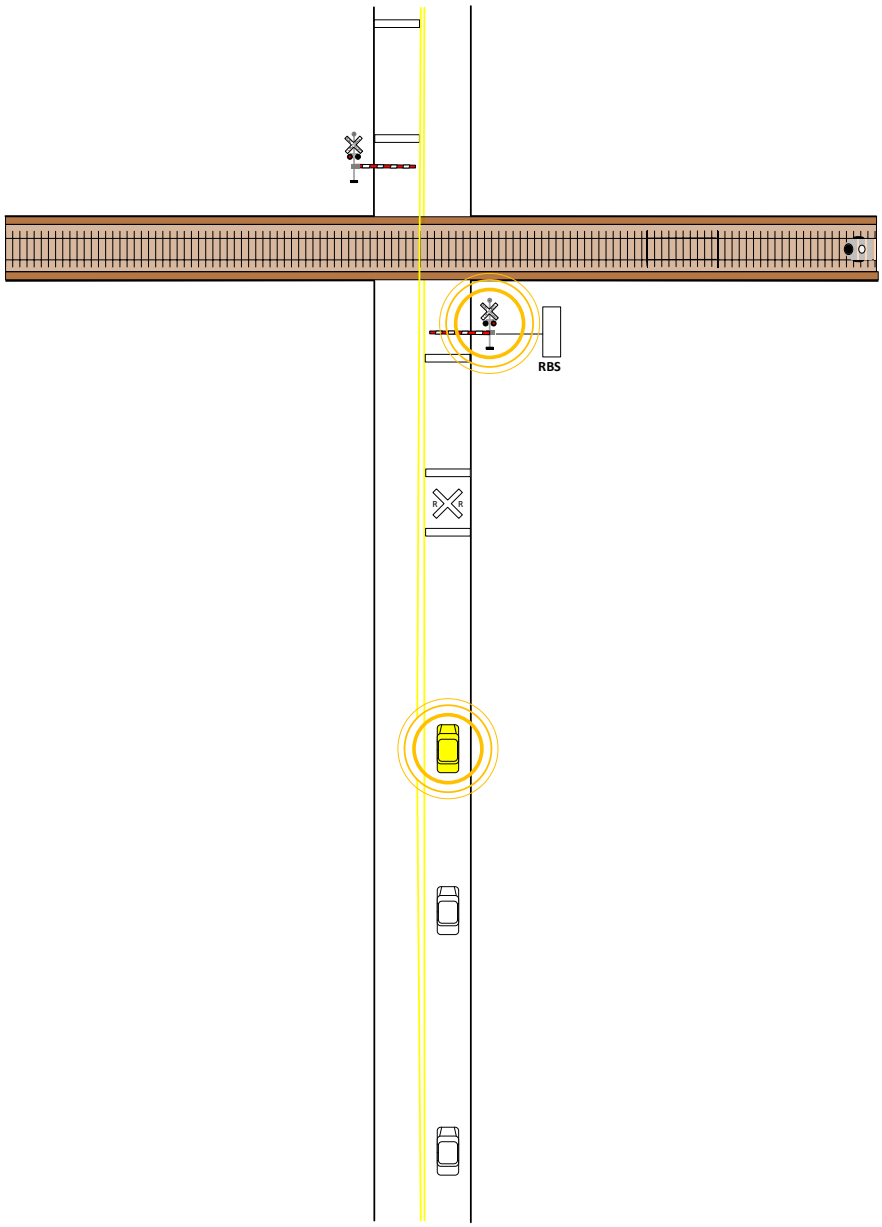

Figure 10. CV Scenario 2

CV Scenario 3: Vehicle is Stopped within the Hazard Zone of an Equipped HRI; HRI Protection System is Active or Becomes Active

1. A CV is stopped within the HRI Hazard Zone.
2. A train is approaching, protective warning device have been activated .
3. 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.

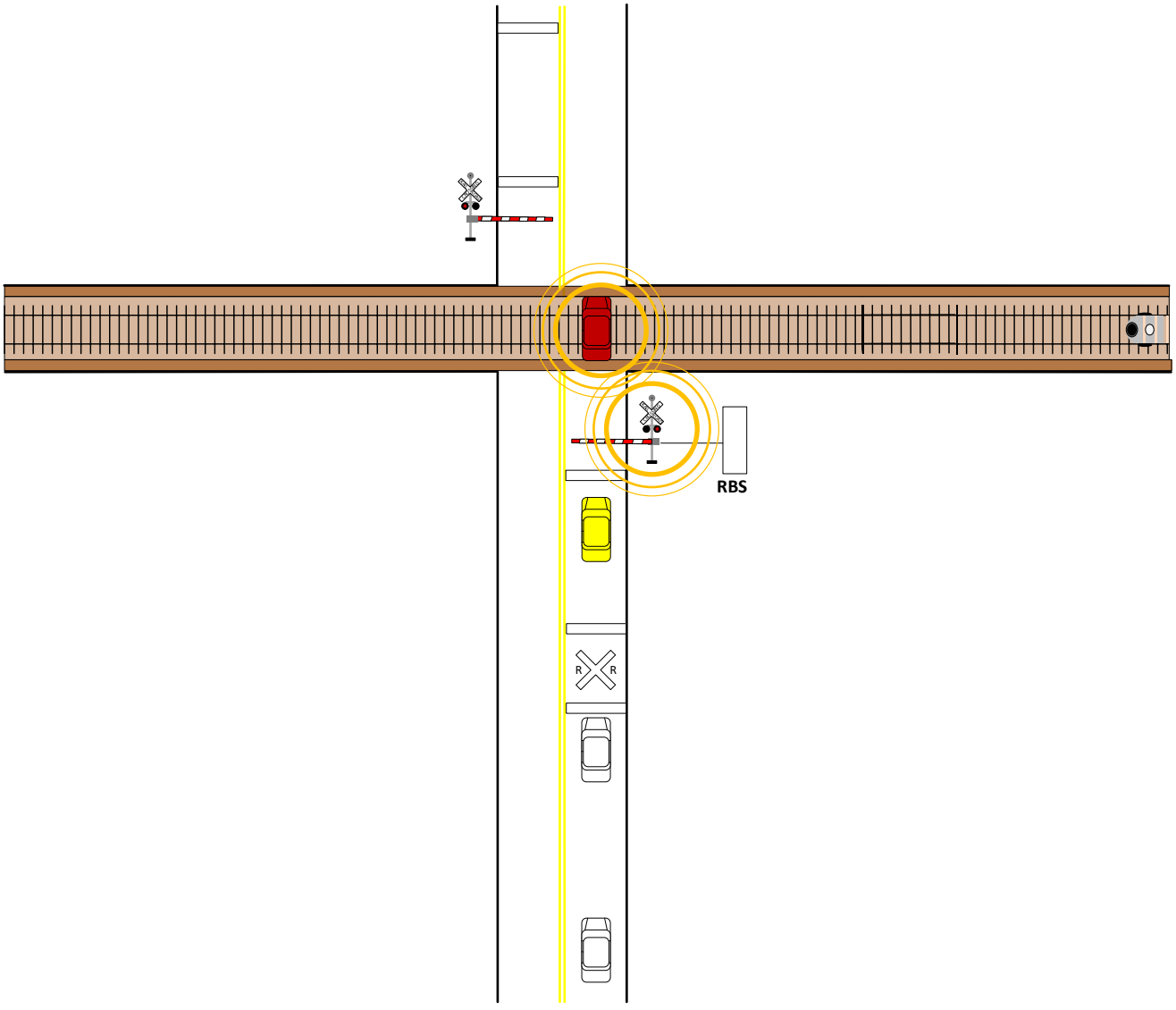

Figure 11. CV Scenario 3

CV Scenario 4: Vehicle is Stopped within the Hazard Zone of an Equipped HRI; HRI Protection System is not Active

1. A CV is stopped within the HRI Hazard Zone.
2. The protective warning device have not been activated.
3. The DVI issues a Clear HRI warning that directs the vehicle operator to clear the HRI Hazard Zone immediately.

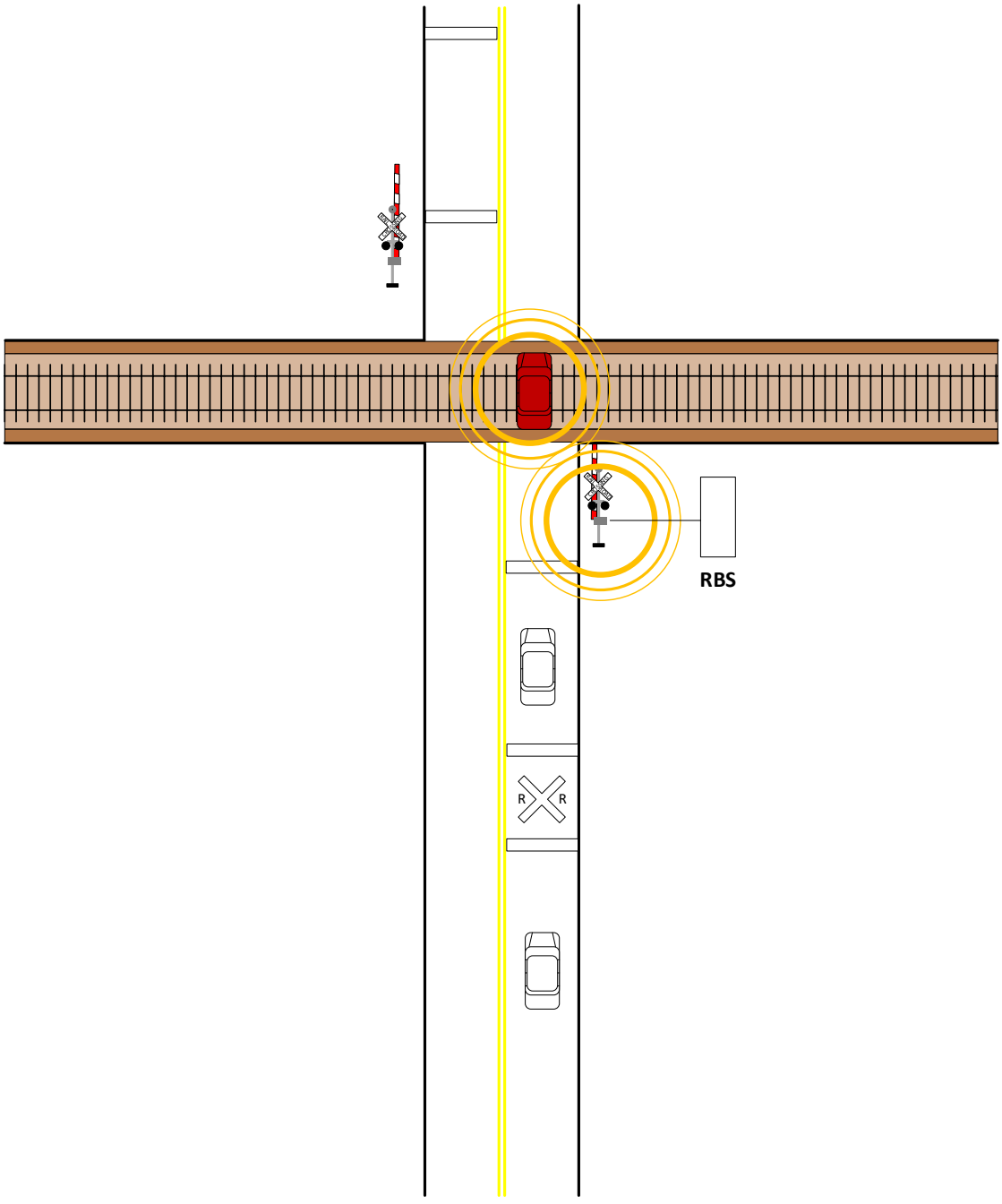

Figure 12. CV Scenario 4

Cloud-Based System Scenarios

The following scenarios provide an overview of applications that could take advantage of the information available from the CBS. The development of these applications is outside the scope of this SRS. These applications will however be conceptualized under this SRS for the purpose of facilitating their future inclusion in the testing and verification of RCVW requirements. A more complete description of additional potential uses and applications leveraging the information provided by the CBS can be found in Appendix D – Potential Cloud Based Scenarios. The figures presented in each scenario are a graphic example of the scenario and are not meant to reflect the final design of the function.

Use Case 1 – Navigation System HRI Notification

1. A user enters a destination into a vehicle's navigation system. The navigation system server has included an HRI in its proposed route.
2. The navigation system server accesses its CBS data to provide information on that HRI. This information will determine the actions taken once the navigation system client is within a predetermined radius of the HRI.
3. When the navigation system client is within a pre-determined radius from the HRI, it checks its previously received HRI data. If the data indicates that the HRI is equipped with an RBS connected to the CBS, the navigation system client will request time-stamped HRI activation status information from its server.
4. If the CBS data also indicates a verifiable data connection to the HRI's RBS exists, the navigation system client provides the following:
    a. A notice indicating the presence of an HRI in route
    b. Time-stamped activation status of the HRI warning devices (activated/deactivated)
5. If the CBS had indicated that the data communications between the RBS and CBS are not verifiable, the navigation system provides the following:
    a. A notice indicating the presence of an HRI in route
    b. A notice indicating "Status Unknown"
6. If the HRI is not equipped with an RBS connected to the CBS, the navigation system provides the following:
    a. A notice indicating the presence of an HRI in route
    b. A notice indicating "Status Unknown"
7. As the vehicle departs the crossing or changes route, the notice will disappear.

Figure 13 and Figure 14 show a graphical representation of this function.

Figure 13. HRI Active - Vehicle Navigation System

Figure 14. HRI Status Unknown - Vehicle Navigation System

Use Case 2 – Navigation System HRI Attributes

1. A user enters a destination into a vehicle's navigation system. The navigation system server indicates that the proposed route includes an HRI.
2. The navigation system client requests its server to provide the server's CBS-acquired information for that HRI.
3. The vehicle's navigation system provides a feature that allows the user to decide whether to receive notifications related to the attribute "Low-grade Crossing" of an HRI in route or not. In this case, the feature is enabled.
4. The navigation system client receives CBS-acquired data from its server indicating that the HRI in the route has a "low-grade crossing" attribute.

5. Prior to proceeding, the vehicle's navigation system issues a notice informing of the HRI attribute allowing the user to select an alternative route or continue.

Figure 15 show a representation of this function.

Figure 15. HRI Attribute - Low Grade Crossing

Use Case 3 – Simulated Traffic Management Center HRI Activation Notification

1. The Traffic Management Center (TMC) is a subscriber of the CBS and monitors several traffic intersections and RBS-RCVW equipped HRIs within the territory.
2. The warning devices of one of these monitored HRI activates. The CBS notifies the TMC of the activation of the warning devices by pushing the HRI ID and the activation status update.
3. The TMC receives the information, generates a notification and a pop-up window activates providing live video feed of the approach to the HRI. The TMC personnel can use this information to monitor traffic patterns and if needed modify adjacent traffic signal phase timings.
4. Once the HRI warning devices deactivate, the CBS discontinues the push of information.

Figure 16 shows representation of this function.

Figure 16. Traffic Management Center – HRI Activation

System Overview

The blocks in Figure 17 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. A more detailed system breakdown is provided in Chapter 4.

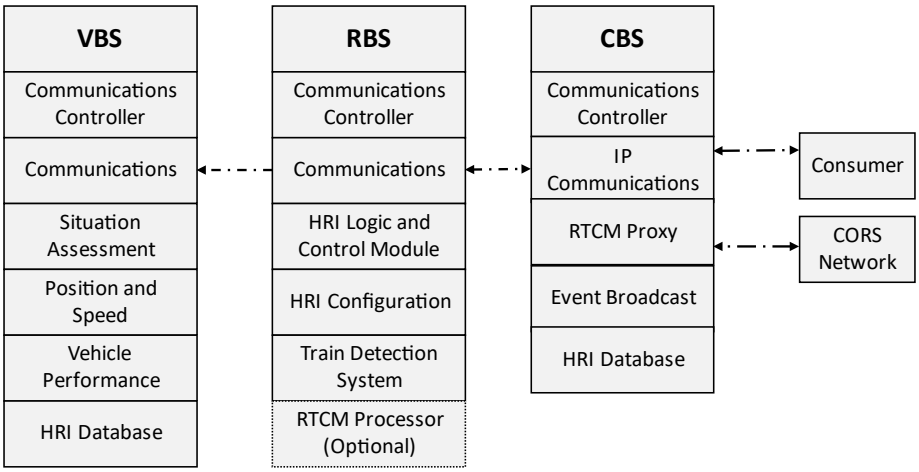

Figure 17. Functional Elements of RCVW

Chapter 2 Referenced Documents

Code of Federal Regulations (CFR)

- 49 CFR 234, “Grade Crossing Signal System Safety and State Action Plans”
- 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, Docket No. FRA–2011–0028, Notice No. 3], RIN 2130–AC27 “Positive Train Control Systems”

U.S. Department of Transportation

- FHWA-JPO-16-408 ”Vehicle-to-Infrastructure Rail Crossing Violation Warning: Concept of Operations”
- FHWA-JPO-18-609 “Vehicle-to-Infrastructure Prototype Rail Crossing Violation Warning Application. Project Report.“
- DOT FRA ORD-22/07 “Rail Crossing Violation Warning Application – Phase II”

Institute of Electrical and Electronic Engineers (IEEE)

- IEEE1570 (2002) IEEE Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection
- IEEE 1362-98 (R2007), Guide for Information Technology, System Definition, Concept of Operations (ConOps) Document
- 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)
    - IEEE 1609.0-2019 – IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture
    - IEEE 1609.2-2016 – IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Security Services for Applications and Management Messages
    - IEEE 1609.3-2020 – IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services

- IEEE 1609.4-2016 – IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Multi-Channel Operations
- IEEE 1609.12-2019 – IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Identifiers

Society of Automotive Engineers (SAE)

- SAE J2735_202211 V2X Communications Message Set Dictionary
- SAE J1757/1_202108 Standard Metrology for Vehicular Displays
- SAE J2402_201001 Road Vehicles – Symbols for Controls, Indicators, and Tell-Tales

National Electrical Manufacturers Association (NEMA)

- NEMA TS 2-2021 v.03.08 Standard for Traffic Controller Assemblies with NTCIP Requirements.

American National Standards Institute (ANSI)

- ANSI/TIA/EIA-422-B Electrical Characteristics of Balanced Voltage Differential Interface Circuits.

Human Factors Guidelines

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

Chapter 3 System Description

The operational objectives of RCVW are dependent on the following major factors:

- For the RCVW system as a whole
    1. Data processing and transmit-receive latencies
    2. Compatibility with all types of vehicle classes
    3. Integrity, availability, and reliability of the data exchanged between subsystems
    4. Suitability of in-vehicle alerting system to licensed drivers

- The VBS
    1. The accuracy of the vehicle location information
    2. The accuracy of the vehicle speed data
    3. The data processing latencies
    4. RBS data reliability
    5. The compatibility of the system with all vehicle types
    6. The effectiveness of the RCVW system alerts and warnings

- The CBS
    1. The reliability of the CBS (non-RBS) HRI data
    2. The availability of the CBS (non-RBS) HRI data
    3. The availability of the HRI RBS data
    4. The reliability of the HRI RBS data
    5. The data processing latencies
    6. The RBS-BCN[2]-CBS link(s) latency

- The RBS
    1. The compatibility with all types of HRIs
    2. The reliability of the data communicated
    3. The data transmit-receive latencies

RCVW 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…” or “The CBS components shall…”. The following shows a general description of the RCVW system requirements. A detailed list of requirements can be found in Chapter 5 Requirements summary.

For the RCVW to effectively perform its functions, it shall comply with the following:

- The RCVW RBS shall be compatible with all types of HRI controllers.
- The RCVW VBS shall be compatible with all types of vehicles.

[2] BCN: Backhaul Communication Network

- The RCVW software and hardware shall employ methods to ensure secure communications and prevent physical access to the system without impacting system performance.
- RCVW communications for both CV and cloud applications shall follow industry standards.
- The RCVW shall be informed by the guidelines that define the placement of warning signs and suggested vehicle driver's visual range when designing the HRI approach zone limits.
- The placing of RCVW antenna(s) shall provide optimum, within practical limits, of site-specific conditions, *bidirectional* line-of-site (LOS) for approaching roadway vehicles.

To effectively perform the RCVW functions, the RBS shall comply with the following:

- The RBS shall be designed to interface, and operate, with all train detection systems without producing or being susceptible to electromagnetic interference (EMI)
- The RBS shall operate using 60 Hz, 115VAC power as the primary power source.
- The RBS shall execute periodic Built-in Self-Test (BIST) to determine the functioning state of critical components.
- The RBS shall execute self-recovering routines to recover from system failures.
- The RBS shall maintain system logs.
- The RBS shall (when on-site configured to do so) produce and broadcast RTCM messages to the VBS.
- The RBS shall (when on-site configured to do so) receive and broadcast RTCM corrections it receives from the CBS to the VBS.

To effectively perform the RCVW functions, the RBS shall transmit the following HRI information to the VBS:

- The RBS shall broadcast the HRI ID and HRI activation status (active/inactive) to the VBS via radio at a rate of ten times per second.
- The RBS shall broadcast the HRI Geometry including HRI geolocation to the VBS via radio at a rate of once per second.
- The RBS shall broadcast the location-error-correction data to the VBS via radio at the rate it receives or produces them, but not more than once per second
- The RBS shall broadcast the functioning status of its connection to the HRI Controller (When an IEEE-1570 device is present).
- The RBS shall stop sending SPaT to VBS and CBS when a connection failure to the HRI controller is detected.
- The connection status between the RBS and the HRI controller shall be broadcasted to the CBS via a diagnostic message.

The above cited data will enable the VBS to perform the following:

- The VBS shall determine when the vehicle has entered the Approach Zone, or Hazard Zone, of an RCVW RBS equipped HRI.
- When an RCVW VBS equipped vehicle is within the Approach Zone of an RCVW RBS equipped HRI, the VBS shall determine when to inform the driver that the HRI is, or becomes, active.
- The VBS shall determine if appropriate action to stop the vehicle short of the HRI Hazard zone is being performed by the driver.

- The VBS shall issue a warning if the system detects that appropriate action to stop the vehicle short of the HRI Hazard Zone is not detected.
- When a RCVW VBS equipped vehicle is stopped within the HRI Hazard Zone and the *HRI is or becomes active*, the VBS shall issue a Clear HRI warning (crash imminent) to clear the crossing immediately.
- When a RCVW VBS equipped vehicle is stopped within the HRI Hazard Zone and the *HRI is not active*, the VBS shall issue a Clear HRI warning to clear the crossing immediately.
- The VBS shall determine when there is a communication issue with the RBS.
    1. HRI Geometry data reception rate is less than once per second
    2. HRI activation status (including HRI ID) data reception rate is less than what is programmed in a user configurable parameter
    3. “Current” RTCM corrections are not available
    4. HRI configuration has not been received
    5. The IEEE 1570 device, when present, is non-responsive.

To effectively perform the RCVW VBS functions, the VBS shall comply with the following:

- All alerts and warnings produced by the VBS shall be suitable for all licensed drivers and vehicle classes and follow industry guidelines.
- The VBS shall receive and process RTCM corrections to improve vehicle location accuracy.
- The VBS shall provide a Driver-Vehicle interface and connectivity to standard Original Equipment Manufacturer (OEM) vehicle displays.
- The VBS shall not interfere with on-board vehicle safety systems or wayside infrastructure systems.
- The RCVW VBS shall detect the approach to an RCVW RBS equipped HRI by means of a database that contains locations and IDs of known RCVW equipped RBSs.
- The RCVW VBS algorithm shall be designed to account for operation in all weather, road surface and visibility conditions.

The RBS shall transmit the following HRI information to the CBS:

- The RBS shall broadcast the HRI geometry including HRI geolocation and HRI ID to the CBS via the internet at a rate of once per second.
- The RBS shall broadcast the HRI ID and HRI activation status (active or inactive) to the CBS via the internet at a rate of 10 times per second.
- The RBS shall broadcast system diagnostics to the CBS via the internet at a rate of once per second. These messages shall include:
    1. HRI ID
    2. Broadcast rate of HRI geometry messages
    3. Broadcast rate of HRI activation status messages
    4. Broadcast rate of RTCM corrections messages
    5. System performance parameters

When requested by an authorized user, the CBS shall provide the following information:

1. Current HRI activation status (active or inactive)
2. Transmission rates of RCVW related messages from a given RBS
3. HRI geometry including HRI geolocation and HRI ID

4. Current RBS diagnostics report
5. An array of RCVW RBS equipped HRIs and their attributes within the boundaries of a specified location and radius

To effectively perform the RCVW CBS functions, the CBS shall comply with the following:

- The availability of the CBS shall not be less than 0.9999.
- The CBS shall employ methods to only accept information from authorized RCVW RBS equipped HRIs.
- The CBS shall connect to and retrieve RTCM correction data from available Continuously Operating Reference Stations (CORS).
- The CBS shall broadcast site specific RTCM corrections to each RBS.
- The CBS shall relay RTCM corrections to the RBS which they apply to.
- The CBS shall maintain a database of geospatial locations and IDs of HRIs along with site-specific attributes.

Environmental Specifications

The RBS shall comply with all environmental requirements specified herein.

a. Operating temperature: -34°C to 74°C.
b. Storage temperature: -45°C to 85°C.
c. Relative humidity: 95% condensing over the temperature range +4.4°C to 43.3°C.
d. Rain: The RBS 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.
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 RBS 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.)
h. Transportation shock and vibration (RBS packaged for shipment): The RBS 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 RBS shall be immune to Radio Frequency (RF) Electromagnetic Interference (EMI) per SAE J1113.
j. Electrostatic Discharge RBS: The RBS 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 shall be based on accepted CV industry and technology standards. As such, there are CV constraints that apply to RCVW:

- Radios shall follow the IEEE 1609 Standards for Wireless Access in Vehicular Environments (WAVE).

- CV Radios shall be able to communicate using the latest approved technology by the Federal Communications Commission (FCC) for use by automotive safety systems[3].
- The Intelligent Transportation Systems (ITS) CV radios shall transmit at a frequency of 5.9 GHz[4] 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 – Potential ITS Radio Broadcast Restriction Zones.

Assumptions and Dependencies

The following are system assumptions and dependencies that contribute to the current RCVW system functionality:

- The system at this point only provides information of trains as they are detected by the HRI train detection system. Other rail crossing safety applications may require the capability to correlate the real-time position of trains as they approach an HRI.
- To achieve the objectives of the RCVW vehicle safety application, roadway vehicles must be equipped with ITS CV technology, and drivers must respond appropriately to in-vehicle alerts/warnings.
- The overall effectiveness of RCVW safety application depends on the roadway vehicle operator being able to respond to the warning appropriately and to do so 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 such as:
    - Situational awareness of the roadway vehicle operator immediately prior to the warning
    - Road surface and grade
    - 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.

To achieve the full effectiveness of the CBS RCVW concept, the CBS depends on the following factors:

- Alternative methods for train detection in passive HRIs
- The availability and reliability of the information stored and provided by the CBS
- CBS communications and protocols complying with industry accepted standards
- Access to a BCN

Based on the CV concept, the RBS component of the RCVW system shall include the following:

- A WAVE compliant radio system
- Industry standard unlicensed-band wireless transceiver(s)
- A process and control system capability that includes the following modules:

[3] At the time of the publishing of this document, the FCC has ruled to phase out Dedicated Short Range Communications technology and substitute it with Cellular Vehicle-to-Everything. See Dedicated Short Range Communications (DSRC) Service | Federal Communications Commission (fcc.gov)

[4] Cellular Vehicle-to-Everything (V2X) technologies operate in the 5.895-5.925 GHz (5.9 GHz) band.

- Industry standard wireless communication interfaces, to enable remote access of RBS operational status and remote system resets as well as downloads of software updates
- Both wired and wireless connection to a BCN
- A communication interface to communicate with an on-site Maintenance Data Terminal (MDT)
- HRI controller preemption signal interface(s)

Operating Modes

The RBS component of the RCVW system 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 system associated equipment and software operates normally when a roadway vehicle and/or train are approaching an HRI.

The RCVW shall transition to a System Failure Mode when:

- HRI geometry and activation status is not received at the required rate as a result of
  - RBS and/or VBS software failure
  - C-V2X communication failure
  - Detectable loss of connectivity with the HRI controller
- The VBS is not receiving location information at the required rate as a result of
  - VBS software failure
  - VBS GNSS module failure
  - GNSS satellite failures
- The VBS is not in RTK mode (fixed or floating) as a result of
  - RBS/VBS/CBS software failure
  - BCN link between RBS and CBS failure resulting in VBS failure to receive RTCM corrections
  - C-V2X communication failure
  - VBS/RBS GNSS module failure

The transition from normal operation to system failure mode is only directly detectable on the VBS. Cloud-based applications may be able to indirectly detect and report a subset of these through the CBS.

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 system but are expected to be implemented in a future phase.*

Startup and RCVW System Validation Scenarios

Conditions: *After the RBS has been installed and connected to the CBS and before RCVW System is put in service, it is needs to execute a system validation testing. System validation testing will ensure accuracy and the integrity of communications between: the RCVW RBS and a VBS-equipped roadway vehicles, and between the RBS and the CBS. A maintenance-system equipped vehicle 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. At the same time, the data broadcast to the CBS from the RBS will be logged in a cloud database for future 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:

- **Cloud data latency:** The cloud shall receive and store HRI operational and activation status messages and HRI Geometry messages. The time of reception of a change-in-state of HRI activation status messages will be recorded and compared to the time it was issued by the RBS to calculate latencies.
- **Coverage Validation Data:** The VBS of the maintenance vehicle shall acquire and record RBS 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 shall approach and cross the HRI comparing the position data that its VBS is acquiring with relevant HRI infrastructure locations. If the correlation is acceptable, ± 1.5 meter(s), it shall communicate its working/current positioning correction data to the RBS.
    - While approaching the HRI at the posted speed limit, the maintenance vehicle's VBS shall receive the simulated HRI activation status message. The time that the maintenance vehicle's DVI displays the alerts shall be recorded and subsequently correlated to the maintenance vehicle's VBS derived coordinates when the alert information was triggered. The timing of the warnings 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 System from Validation Mode to Normal Operation Mode.

Normal Operation Scenarios

Normal operation includes scenarios in which the RCVW System is not in Startup/Validation, System Failure, or Maintenance Mode, and in which the RCVW RBS equipment is performing normally. The configurations, scenarios, and associated alerts for RCVW RBS 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 protective warning device that the driver 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.

Communication Errors

Communication failure means that the VBS does not receive sufficient number of messages per second 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.

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 resulting in “too late”, or “too early”, warnings and alerts.

Communication Errors and Geospatial Information faults will be presented to the vehicle driver over the CV safety application.

RBS Diagnostics

RBS System diagnostic messages informing on the status of the communication rates, software module health and HRI controller connection will be communicated to the CBS where they will be logged and relayed to subscribed users.

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 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 system, partial functionality that addresses system resilience is implemented. 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 transmitter power levels. System status and failures are broadcast over the CBS for subscribed users to be notified.*

Performance

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

Interfaces

The RCVW shall include the following protocol and connector interfaces:

- Low latency radio communication interface between the VBS and RBS
- Low latency Transmission Control Protocol/Internet Protocol (TCP/IP) based communication between the RBS and CBS
- A Driver-Vehicle Interface to produce alerts and warnings
- Low latency VBS means to receive and process GNSS signals

- Low latency RBS means to receive and process GNSS signals
- Cloud-based interface to a Network Transport of RTCM via Internet of RTCM via Internet Protocol Data and Data Structures

The RCVW system shall conform to the data structures provided in Table 1 through Table 13

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*. The information presented in Table 1 to Table 17 have been adapted from the FRA Data Dictionary for External Use Grade Crossing Inventory System (GCIS) v3.2.0, Release Date: 06/21/2022[5]

Table 1. Data Flow Messages

Data Flow	ITS Message Standard	Subsystem Involved	ITS Standard Message Set
HRI Activation Status	SAE J2735	RBS VBS CBS	MSG_SPAT
HRI Geometry Message	SAE J2735	RBS VBS CBS	MSG_MapData
Positioning Data	NMEA 0183	VBS	GPGGA GNGSA GPGSV GPRMC GPZDA
Positioning Correction	RTCM SC-104	RBS VBS CBS	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*	RBS VBS CBS	MSG_RTCMCorrections
RBS System Diagnostics	To be determined	RBS CBS	New Message Set Required

[5] https://safetydata.fra.dot.gov/gcis/Help/ReferenceDocuments/GCIS_Data_Dictionary_External_Use_v3-2-0-152_Rel_06-21-2022.pdf

Data Flow	ITS Message Standard	Subsystem Involved	ITS Standard Message Set
HRI rail crossing operational status (4904)	IEEE-1570	RBS	HRI Rail Crossing Operational State
HRI Registration (Cloud Message)	To be determined	RBS CBS	New Message Set Required
HRI Activation Status Message (Cloud Message)	To be determined	CBS	New Message Set Required
Known HRI ID Message (Cloud Message)	To be determined	CBS	New Message Set Required

Table 2. HRI Activation Status – Data Elements

Data Elements	Data Type
HRI_ID	Int: 32 bit
UT_Time_Stamp	Char: hhmmss.ss
UT_Date_Stamp	Char: ddmmyy
HRI Status	Int: 32 bit
Approach ID0	Int: 8 bit
Approach ID1	Int: 8 bit
Approach ID2	Int: 8 bit

Table 3. HRI Geometry Messages – Data Elements

Data Elements	Data Type
HRI_ID	Int: 32 bit
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)
Altitude	Int: 16 bit (signed)
Road grade and surface parameters	Char: 252 byte limit
Lane_Number	Int: 8 bit
Lane_Width	Int: 16 bit

Table 4. Global Positioning System Fix Data (GPGGA) – Data Elements

Data Elements	Data Type
UTC_position_fix (time)	Char: hhmmss.ss
Latitude of fix	Float: nnnn.nn
N or S	Char: A
Longitude of fix	Float: nnnnn.nn
E or W	Char: A
Quality Indicator	Int: 8 bit
Number of Satellites used	Int: 8 bit
UT date	Char: ddmmyy

Data Elements	Data Type
Horizontal Dilution of Precision	Float: n.n
Antenna Altitude	Float: n.n
Units of antenna altitude	Char:M
Geoidal Separation	Float: n.n
Units of geoidal separation	Char: M
Age of Differential Corrections	Int: 8 bit
Differential reference station ID	Char: AAAA

Table 5. Dilution of Precision and Active Satellite Information (GNGSA) – Data Elements

Data Elements	Data Type
Satellite Acquisition Mode	Char: T
Position Mode	Char: N
Satellites Used	Char: N
Position Dilution of Precision	Float: nn.nn
Horizontal Dilution of Precision	Float: nn.nn
Vertical Dilution of Precision	Float: nn.nn
GNSS System ID	Char: N

Table 6. Global Positioning System Satellites in View (GPGSV) – Data Elements

Data Elements	Data Type
Total Number of Messages	Int: 8 byte
Message Number	Char: N
Satellites in View	Int: 8 byte
Satellite Number	Int:8 byte
Elevation	Int: 8 byte
Azimuth	Int: 8 byte
Signal Strength	Int: 8 byte
Signal ID	Char: N

Table 7. Global Positioning Recommended Minimum (GPRMC) Data Elements

Data Elements	Data Type
Current Heading	Float: n.n
Magnetic Heading	Char:N

Table 8. Coordinated Universal Time and Date Information – GPZDA Data Elements

Data Elements	Data Type
UTC Time	Char: hhmmss.ss
Day	Char: NN
Month	Char:NN
Year	Char:NNNN
Local Zone (hours)	Char: NN
Local Zone (Minutes)	Char:NN

Table 9. RBS System Diagnostic – Data Elements

Data Elements	Data Type
HRI_ID	Int: 32 bit
RBS GeometryMAP Message Broadcast Rate	Int: 8 bit
RBS State SPaT Message Broadcast Rate	Int: 8 bit
RBS RTCM Message Broadcast Rate	Int: 8 bit
Software Component ID0 Health	Char:N
Software Component ID1 Health	Char:N
Software Component ID2 Health	Char:N

Table 10. IEEE 1570 Standard Message 4904 – Data Elements

Data Elements	Data Type
HRI ID	Int: 32 bit
Number of Tracks in Crossing	Char: N
HRI Heartbeat	Char: N
Trains Associated with Crossings	Char: N
System Operational	Char: N
Train Presence	Char: N
Warning System Active	Char: N
Preemption Warning Active	Char: N
Exit Gate Presence	Char: N
Exit Gate Up	Char: N
Exit Gate Down	Char: N
Entrance Gate Presence	Char: N
Entrance Gate Up	Char: N
Entrance Gate Down	Char: N
Preemption Design Time	Char: sss
Train Sequence Number	Char: N
Direction	Char: N
Island Occupied	Char: N
Warning System Activation Time	Char: sss
Estimated Time to Warning System Activation	Char: sss

Table 11. HRI Activation Status Message - Message Data

Data Elements	Data Type
HRI ID	Int: 32 bit
Latitude of fix	Float: nnnn.nn
N or S	Char: A
Longitude of fix	Float: nnnnn.nn
E or W	Char: A
HRI Preemption Signal Status	Char: T
RSU/RBS Operational State	Char: T
RBS URL	URL: https://...

Table 12. Known HRI ID - Message Data

Data Elements	Data Type
HRI ID	Int: 32 bit
Latitude of fix	Float: nnnn.nn
N or S	Char: A
Longitude of fix	Float: nnnnn.nn
E or W	Char: A

Table 13. HRI Crossing Header - Data Elements

Data Elements	Data Type
HRI ID	Int: 32 bit
HRI Protective warning device Present	Char: A
Agency ID	Int: 32 bit
County Code	Char: NNNNN
Crossing ID	Char: NNNNNNN
Published Report Base ID	Int: 32 bit
State Cde	Char:NN
Created	Char: ddmmyy hhmmss
Created By	Char: 50 byte limit
Last Updated	Char: ddmmyy hhmmss
Last Updated By	Char: 50 byte limit

Table 14. HRI Highway Traffic Control Device - Data Elements

Data Elements	Data Type
HRI ID	Int: 32 bit
AdvWarn	Char: 32 byte limit
AwdIDate	Char: ddmmyy hhmmss
AwHornChk	Char:A
AwHornIDate	Char: ddmmyy hhmmss
Bells	Int: 32 bit
Bkl_FlashPost	Char: A
CFlashType	Char: 32 byte limit
Channel	Char: 32 byte limit
EnsSign	Char: A
Exempt	Char: A
FlashNov	Int: 32 bit
FlashOther	Int: 32 bit
FlashOtherDes	Char: 256 limit
FlashOv	Int: 32 bit
FlashPai	Int: 32 bit
FlashPost	Int: 32 bit
FlashPostType	Char: 32 byte limit
GateConf	Char: 32 byte limit
GateConfType	Char: 32 byte limit
GatePed	Int: 32 bit
Gates	Int: 32 bit
HwtrfPsig	Char: A
HwtrfPsigIndis	Int: 32 bit
HwtrfPsigsdis	Int: 32 bit

Data Elements	Data Type
HwynrSig	Char: A
HwyTrafSignl	Char: A
Intrprmp	Char: 32 byte limit
Led	Char: 256 byte limit
Low_Grnd	Char: A
Low_GrndSigns	Int: 32 bit
MonitorDev	Char: 32 byte limit
NoSigns	Char: A
OthDes1	Char: 10 byte limit
OthDes2	Char: 10 byte limit
OthDes3	Char: 10 byte limit
OthSign	Char: A
OthSign1	Int: 32 bit
OthSign2	Int: 32 bit
OthSign3	Int: 32 bit
PaveMrkIDs	Char: 32 byte limit
PrempType	Char: 32 byte limit
PrvxSign	Char: A
ReportBaseId	Int: 32 bit
Sdl_FlashPost	Char: A
SpecPro	Char: 20 byte limit
StopStd	Int: 32 bit
XBuck	Int: 32 bit
YieldStd	Int: 32 bit
WdCode	Char: N
Created	Char: ddmmyy hhmmss
Last Updated	Char: ddmmyy hhmmss
Last Updated By	Char: 50 byte limit

Table 15. HRI Location and Classification - Data Elements

Data Elements	Data Type
HRI ID	Int: 32 bit
BlockNumb	Char: 6 byte limit
CityCD	Char: 10 byte limit
CntyCD	Char: 10 byte limit
DevelTypId	Char: 32 byte limit
Highway	Char: 256 byte limit
HscoRrid	Char: NNNN
HwyCont	Char: 10 byte limit
Latitude	Char: 256 byte limit
LLsource	Char: 10 byte limit
Longitude	Char: 256 byte limit
MultFrmsFiled	Char: A
Nearest	Char: 6 byte limit
OpenPub	Char: A
PolCont	Char: 10 byte limit
PosXing	Char: 32 byte limit
Railroad	Char: 32 byte limit
ReportBaseId	Int: 32 bit
RrCont	Char: 10 byte limit

Data Elements	Data Type
RrID	Char: 256 byte limit
RrMain	Char: 32 byte limit
RrNarr	Char: Max
RrNarr1	Char: 256 byte limit
RrNarr2	Char: 256 byte limit
RrNarr3	Char: 256 byte limit
RrNarr4	Char: 256 byte limit
SameInd	Char: A
SameRr1	Char: 32 byte limit
SameRr2	Char: 32 byte limit
SameRr3	Char: 32 byte limit
SameRr4	Char: 32 byte limit
SepInd	Char: A
SepRr1	Char: 32 byte limit
SepRr2	Char: 32 byte limit
SepRr3	Char: 32 byte limit
SepRr4	Char: 32 byte limit
SfxHscoRrid	Char: 4 byte limit
StateCD	Char: NN
StNarr	Char: Max
StNarr1	Char: 256 byte limit
StNarr2	Char: 256 byte limit
StNarr3	Char: 256 byte limit
StNarr4	Char: 256 byte limit
Street	Char: 256 byte limit
Ttstn	Char: 6 byte limit
TtstnNam	Char: 256 byte limit
TypeTrnSrvcId	Char: 32 byte limit
TypeXing	Char: 32 byte limit
Whistban	Char: 32 byte limit
WhistDate	Char: ddmmyy hhmmss
XingAdj	Char: A
XingOwnr	Char: 32 byte limit
XngAdjNo	Char: 7 byte limit
XPurpose	Char: 32 byte limit
Created	Char: ddmmyy hhmmss
Created By	Char: 50 byte limit
Last Updated	Char: ddmmyy hhmmss
Last Updated By	Char: 50 byte limit

Table 16. HRI Physical Characteristics - Data Elements

Data Elements	Data Type
HRI ID	Int: 32 bit
ComPower	Char: A
Downst	Char: A
HwynDist	Int: 32 bit
HwyNear	Char: A
HwyPved	Char: A
Illumina	Char: A
ReportBaseId	Int: 32 bit
TraficLn	Int: 32 bit
TrafInType	Char: 32 byte limit
XAngle	Char: 32 byte limit
XSurfaceIDs	Char: 32 byte limit
XSurfDate	Char: MMYYYY
XSurfLength	Int: 32 bit
XSurfWidth	Int: 32 bit
XSurfOthr	Char: 256 byte limit
Created	Char: ddmmyy hhmmss
Created By	Char: 50 byte limit
Last Updated	Char: ddmmyy hhmmss
Last Updated By	Char: 50 byte limit

Table 17. HRI Public Highway - Data Elements

Data Elements	Data Type
HRI ID	Int: 32 bit
Aadt	Float
AadtYear	Char: YYYY
EmrgncySrvc	Char: A
HwyClassCD	Char: 10 byte limit
HwyClassrdtpID	Char: 32 byte limit
HwySpeed	Int: 32 bit
HwySpeedps	Char: 32 byte limit
HwySys	Char: 32 byte limit
LrsMilePost	Char: 256 byte limit
LrsRouteid	Char: 256 byte limit
PctTruk	Float
ReportBaseId	Int: 32 bit
SchlBsCnt	Float
SchlBusChk	Char: A
StHwy1	Char: A
Created	Char: ddmmyy hhmmss
Created By	Char: 50 byte limit
Last Updated	Char: ddmmyy hhmmss
Last Updated By	Char: 50 byte limit

Reliability Maintainability Availability

The following information defines the desired system performance in terms of performing its intended function (reliability), time to perform a repair in case of a failure (maintainability) and the operational probability of the system at a given point in time.

Reliability

The calculated Mean-Time-Between-Failures (MTBF) for the RBS 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 able to isolate faults to a specific module – restore service by replacing it.

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

Availability

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

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

The availability of the CBS shall not be less than 0.9999.

RBS Physical Security

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

Chapter 4 Functional Description

The functional block diagram (Figure 17) provides system developers and developers of other interfacing systems with an overview of the objectives, interactions, and interfaces of each RCVW components. 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 RCVW VBS design is based on the architecture described/specified in detail in Appendices C-1 and C-2 of the CICAS-V Phase I final report[6]. Information that pertains to RCVW is presented herein to describe the context in which RCVW system is likely to be implemented. Figure 18 presents the functional block diagram adaptation of the CICAS-V VBS to an RCVW VBS. This SRS does identify revisions to CICAS 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 18, the VBS is comprised of the following functional modules:

1. Message Exchange Module (MX)
2. Situation Assessment Module (SAM)
3. On-Board Unit (OBU)
4. Driver-Vehicle Interface Module (DVI)

[6] https://www.campllc.org/cooperative-intersection-collision-avoidance-system-for-violations-cicas-v-project/

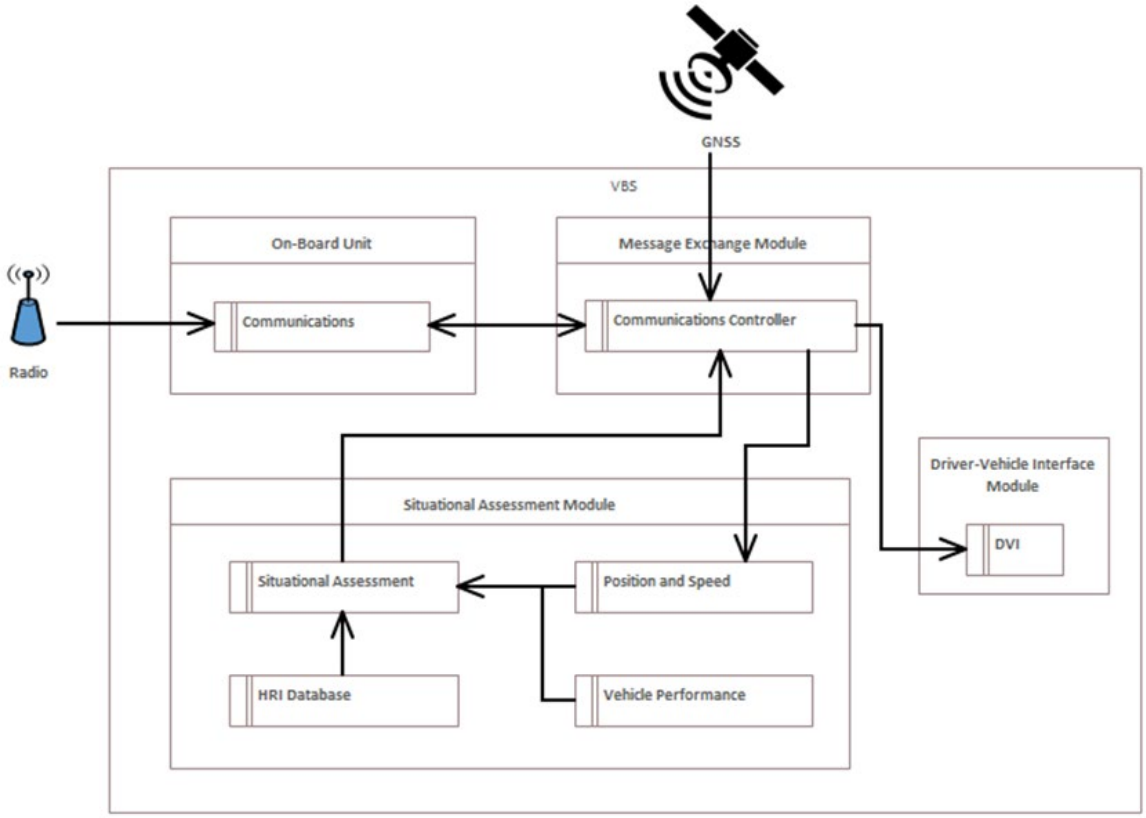

Figure 18. VBS Block Definition Diagram

Message Exchange Module

The MX module handles the exchange of data between external components and the VBS, as well as the internal communication between each VBS component. For example, the MX will manage the flow of V2X messages coming from the RBS to the VBS via the OBU, as well as the positional data from the GNSS receiver and distribute appropriate to the SAM. Likewise, the alerting messages between the SAM and the DVI must pass through the MX. In each example, the goal is to use the MX to produce a common or *neutral* structure to the data that other components can readily understand.

The current performance, i.e., the rate of reception, for each message exchange through the MX module is maintained for diagnostic purposes.

On-Board Unit

The OBU will provide the wireless link to/from the RBS. The functional requirements of the OBU will be those stipulated in the IEEE suite of protocols addressing WAVE and C-V2X specifications. The information flow for an incoming V2X messages is:

RBS RSU (C-V2X radio) → VBS OBU (C-V2X radio) → MX → SAM

Any transmitted messages will follow the reverse information flow and be authenticated in accordance with the WAVE protocol standards. The OBU should maintain performance of the radio for use in diagnostics.

Situation Assessment Module

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

- Speed
- Vehicle acceleration/deceleration rate
- Location with respect to the HRI

The deceleration rate is a function of factors such as:

- Vehicle Type and weight
- Road gradient
- Roadway vehicle performance specifications

When a roadway vehicle is within broadcast range of an RBS in its database, as determined by the local HRI database, the SAM expects to receive RBS broadcast including the HRI Geometry and HRI Activation Status message. If an RBS broadcast is not received, or is missing one of the mandated messages, then an error message is generated.

Using the above information, the SAM will determine if a roadway vehicle approaching or entering/crossing an HRI will warrant issuing an RCVW . If it is predicted that a violation is about to occur, the SAM will issue a warning via the VBS DVI. All history of operational state transitions will be available for system diagnostics.

Driver-Vehicle Interface Module

The DVI will control the video display, audio, and/or haptic devices. The current operational state of this device should be part of the system diagnostics.

The DVI 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.

RBS

Figure 19 presents the functional adaptation of CICAS-V RBS to RCVW. The RBS shall be comprised of the following functional modules (and required supporting devices):

1. Integrity Module
2. Roadside Communications Module (RCM), providing communication interfaces for:
    - Industry standard wired and unlicensed-band wireless transceivers (IEEE 802.3 & IEEE 802.11)
    - Industry standard broadcast structure (RSU 4.1 & CTI 4001 v01.00)

- Wireless Access in Vehicular Environments (IEEE 1609)
- TCP/IP
- TIA/EIA-422-B Electrical Characteristics of Balanced Voltage Differential Interface Circuits
- Security Credential Management System (SCMS)

3. RCVW Logic & Control Module (RLCM)
4. HRI Geometry Module
5. Base Station Module

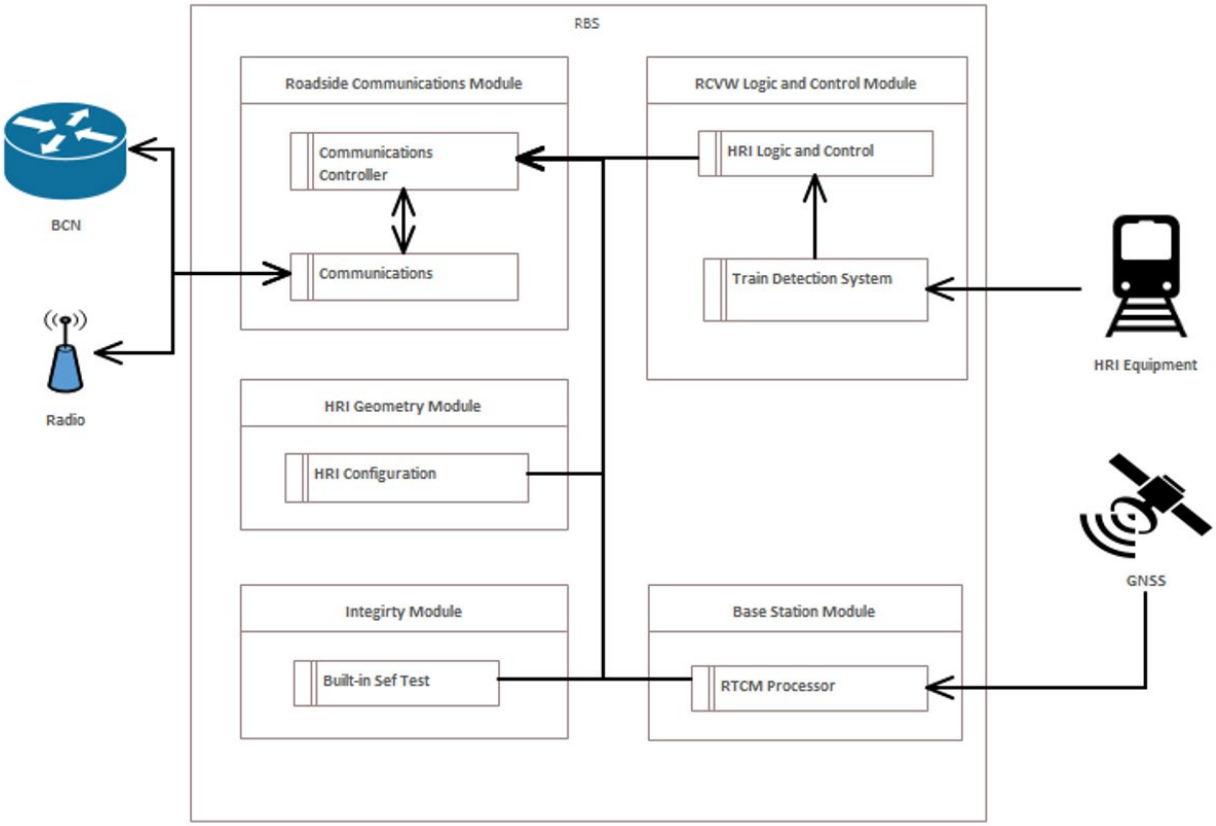

Figure 19. RBS Block Definition Diagram

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 RSU.

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 diagnostic messages containing RBS status one time per second to the CBS.

Roadside Communications Module

The RCM shall interface and manage communications with all external devices. Messages to be transmitted and received by the C-V2X radio or other roadside network, shall be routed and managed by this module.

The RCM shall format messages that are to be transmitted by the C-V2X radio to roadway vehicles in accordance with the IEEE 1609 suite of protocols. Messages sent to the CBS via a roadside network shall be formatted and transmitted in accordance with industry standard TCP/IP protocols. Messages that are to be received by the RCM shall be in accordance with the suite of WAVE protocol standards for wireless communications and TCP/IP for roadside network communications.

The RCM messages exchanged with OBUs and CBS shall include the following types of information:

- RBS operational status and HRI ID
- HRI geometry (MAP)
- HRI activation status (active or inactive)
- RTCM correction data

RBS RCVW Logic and Control Module

The RLCM shall be initialized by the Integrity Module. The RLCM is connected to the train detection system at the HRI to receive the preemption signal and is constantly sending HRI status messages to the RCM. When the preemption status changes, the RLCM shall initiate a change to the HRI status message. Specific to this SRS, the RBS shall be able to process up to four HRI controller preemption signals (four trains approaching) from a single HRI.

RBS HRI Geometry Module

The geometric HRI description data, which defines the HRI approach and hazard zones, is manually created and stored in the HRI Geometry Module. This module then creates a HRI geometry message every second and sends it to the RCM. The HRI Geometry Module shall be initialized by the Integrity Module.

Base Station Module

The Base Station Module utilizes GNSS data to determine localized RTCM corrections. These are then routed through the RCM for transmission to the VBS. This module is enabled during installation if CBS RTCM proxy service is not provided.

CBS

Figure 20 presents the cloud-based component for mobile application connectivity to the RBS. The CBS shall be comprised of the following functional modules (and required supporting devices):

1. Cloud Communications Module (CCM)
2. HRI Event Manager (HEM)
3. RTCM Proxy
4. HRI Database

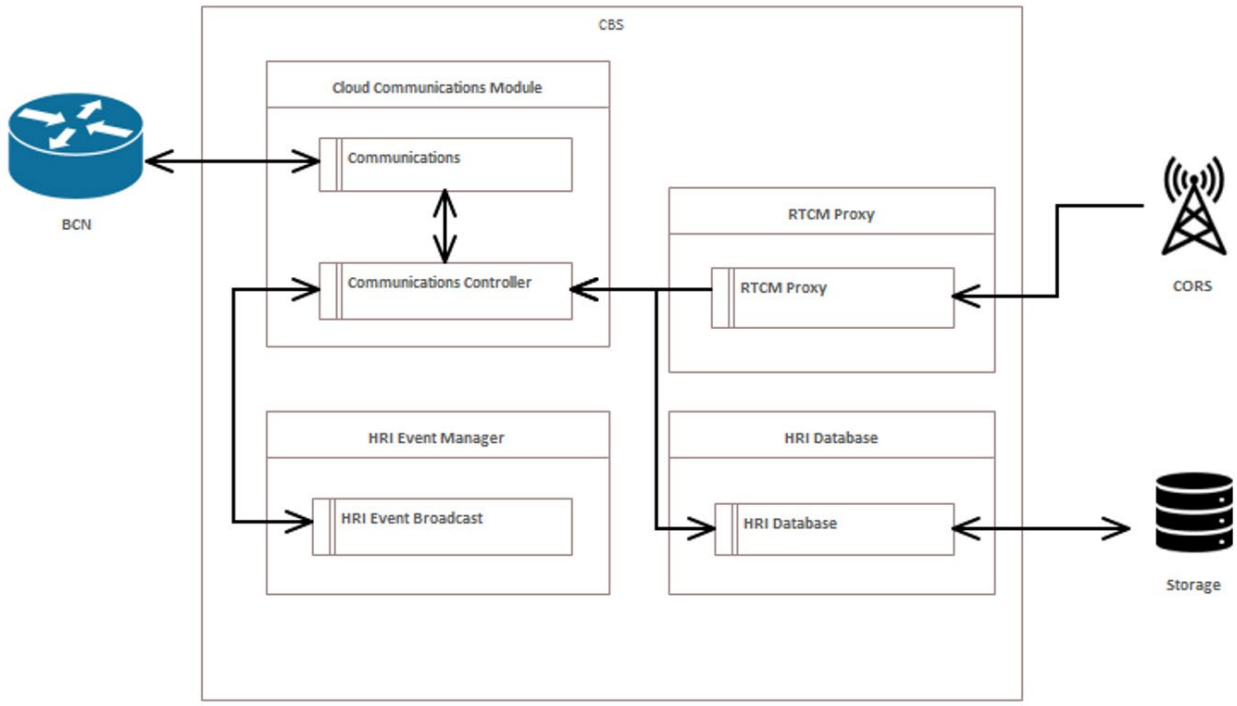

Figure 20. CBS Block Definition Diagram

Cloud Communications Module

The CCM serves to receive messages from the RBS. The communication protocols are secured both by restrictive network access and certificate-based encryption. All data is received from the RBS and logged to cloud storage in order to maintain the history of the operational status of each RCVW RBS equipped HRI.

HEM

The HEM is responsible for keeping track of the current operational status for each HRI. This includes using incoming HRI activation status messages to capture the transition of crossing from inactive to active and back, as well as using the diagnostic messages to report failure conditions. The HEM generates its own HRI operational status messages in the cloud that indicate when operational status changes for the given HRI.

RTCM Proxy

A secondary use of the CBS is to proxy the positioning correction source for an RBS. This is done in the RTCM Proxy module, which picks up the known location of the RBS and simulates a GNSS signal received at that location in order to retrieve corrections from an appropriate base station. The corrections for that RBS are then forwarded to the RBS via the BCN.

HRI Database

A database of all known HRIs is maintained within the CBS. These include crossings that are RCVW RBS equipped and those that are not. This HRI database can be queried by location and search radius in order to find all HRIs in the vicinity of that location. Although there is no required VBS connection to the CBS in the current design, it may certainly be convenient that the portion of the HRI-RBS database required by the VBS be obtained from the CBS during periods of connectivity.

Chapter 5 Requirements Summary

Not all requirements have direct traceability to the RCVW ConOps needs matrix. Many are implied, many are quite generic in nature and would apply to any concept as it evolves into a physical entity suitable for deployment in the harsh environment of a railroad right-of-way.
Several requirement number no longer appear on the table. The development of the RCVW has resulted in several requirements being removed and their numbers no longer being used.

RCVW System

Table 18 lists all the RCVW overall system requirements.

Table 18. RCVW System Requirements

Number	Requirement	ConOps Stakeholder Needs Reference
RCVW-001	The system shall include a VBS component, a RBS component and a CBS component.	
RCVW-003	The system shall be modular and sufficiently extensible to address all design objectives defined in this SRS.	
RCVW-005	The only point(s) of connection between the RCVW system and the HRI Controller shall be the preemption signal itself or via a third-party device that provides an IEEE 1570-compliant serial interface.	N-012b, N-015
RCVW-007	The VBS On-board Unit (OBU) and RBS Roadside Unit (RSU) shall communicate in compliance with the suite of IEEE-1609 standards/protocols and SAE J2735_202211 Standards.	N-013a

Table 18. RCVW System Requirements (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
RCVW-008	All “over-the-road” licensed vehicles (i.e., vehicles of all vehicle classes) are included.	N-003
RCVW-011	The system shall be compliant with CV Personally Identifiable Information (PII) standards and guidelines.	
RCVW-012	The RBS and the CBS shall communicate in compliance with SAE J2735_202211, IEEE 1609 over a TCP/IP based BCN.	N-013b
RCVW-013	All communications between the RBS and the VBS/CBS shall be secured through the use of authenticated certificates issued through the Security Credential Management System (SCMS).	N-025
RCVW-014	The start of an HRI Approach lane for the purposes of RCVW shall equate to a vehicle driver's visual range of a Grade Crossing as defined by 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.	N-002

Source: Battelle

VBS

Table 19 lists VBS requirements necessary for implementing RCVW.

Table 19. VBS Requirements

Number	Requirement	ConOps Stakeholder Needs Reference
VBS-001	The VBS shall have the capability to produce alerts suitable for all licensed drivers.	N-001
VBS-002	The VBS shall have a human-machine interface (HMI) that is configurable to be audible, visual, both, or neither by the driver.	N-002
VBS-003a	The VBS will present alerts that conform to Campbell et all. (2004) In-Vehicle Display Icons and Other Information Elements, Volume 1: Guidelines and Campbell et all. (2016) Human Factors Design Guidance for Driver-Vehicle Interfaces.	N-002
VBS-003b	The system shall provide two-stage alert messaging consisting of an inform alert, and, if applicable, a warning.	N-001, N-002
VBS-003c	The inform and warning alerts shall be multimodal (visual and auditory) in nature.	N-001, N-002
VBS-004	The VBS shall produce alerts that can be implemented in all vehicle classes and types equipped with appropriate CV technologies.	N-003
VBS-005	The VBS shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the RBS to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters.	N-007, N-014c
VBS-006	The VBS shall process HRI geometry data to determine the geospatial location and the ingress and egress lanes for the HRI.	N-008,N-014c
VBS-007	The VBS shall only produce alerts when the vehicle is in range and approaching a known RCVW RBS equipped HRI.	N-008,N-014c
VBS-007a	A vehicle is considered in range when its current position (accounting for all uncertainties) is within the boundaries of a configurable radius away from a known RCVW RBS equipped HRI.	N-010,N-014c
VBS-007b	The configurable radius in VBS-007a shall not be less than 0.5 km.	N-009.N-017,N-018a

Table 19 VBS Requirements (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
VBS-008	The system shall utilize a driver-vehicle interface (DVI) and OEM displays through standard physical and electrical outputs.	N-002, N-030
VBS-009a	The VBS shall not interfere with any of the onboard safety systems, especially automotive industry automated safety systems	N-027
VBS -009b	The VBS shall not interfere with any existing infrastructure subsystems (traffic control and HRI warning systems)	N-012A, N-012b
VBS-010	The VBS shall determine if the vehicle is within the HRI Hazard Zone and/or the HRI Approach Zone.	N-007, N-010,N-014c
VBS-011b	The VBS shall continually issue unique HRI Approach warnings to the vehicle operator while the HRI safety devices are active and the vehicle is within the HRI Approach Zone but not decelerating sufficiently to stop safely before the HRI using non-emergency braking.	N-002, N-017, N-014c, N-018a
VBS-011c	All VBS *warnings* shall use a dynamic visual icon(s) and intrusive auditory alert(s).	N-001, N-002
VBS-011d	The VBS shall continually issue unique HRI Hazard warnings to the vehicle operator while the HRI safety devices are active and the vehicle is stopped within the HRI Hazard Zone.	N-002, N-010, N-014c, N-016a,N-016b, N-017
VBS-012	The VBS shall continually issue unique HRI Approach informational alert messages to the vehicle operator while the HRI safety devices are active and the vehicle is within the HRI Approach Zone.	N-010, N-014c, N-016a, N-016b, N-018a
VBS-12a	The VBS shall continually issue unique HRI Hazard informs to the vehicle operator while the HRI safety devices are not active and the vehicle is stopped within the HRI Hazard Zone.	N-010, N-014c , N-016a,N-016b, N-017
VBS-013	All VBS inform alerts shall use static visual icons and audible alert(s).	N-002
VBS-014	The VBS shall process the HRI activation status message in the context of its position within the HRI Hazard Zone or HRI Approach Zone, and utilizing the vehicle dynamics data, shall determine if an alert or warning is warranted.	N-004,N-010, N-014c, N-017

Table 19 VBS Requirements (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
VBS-015	Warnings and alerts shall be generated with regard to: 85th percentile driver response time, vehicle characteristics (i.e., vehicle class and antenna offset), and vehicle dynamics	N-002, N-004,N-017, N-018a
VBS-016	The VBS shall only issue inform alerts and warnings when the positional information (while accounting for all uncertainties) places the vehicle inside the HRI Hazard Zone or the HRI Approach Zone, based on the present HRI geometry.	N-010, N-014c, N-017,
VBS-017	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 HRI becomes inactive.	N-014c, N-017, N-018a
VBS-018	The VBS shall contain a database of geospatial locations and IDs for known RCVW RBS quipped HRIs.	
VBS-018a	The VBS shall continually issue Position Prevalence fault alerts to the vehicle operator when the vehicle is in range of an HRI but the VBS positional information is being received at a lower average rate than what the Positional Prevalence fault parameter indicates.	N-002, N-014c, N-020
VBS-018b	The VBS shall continually issue Position Resolution fault alerts to the vehicle operator when the vehicle is in range of an HRI but the VBS positional resolution remains inferior to floating point or fixed integer RTK.	N-002, N-014c, N-020, N-013d
VBS-018c	The VBS shall continually issue HRI Geometry Prevalence fault alerts to the vehicle operator when the vehicle is in range of an HRI but the HRI Geometry information is being received at a consistent rate under once per second.	N-014c , N-020
VBS-018d	The VBS shall continually issue HRI Activation Status Prevalence faults to the vehicle operator when the vehicle is in range of an HRI but the HRI Activation Status is being received at a lower average rate than what the HRI Activation Status Prevalence fault parameter indicates.	N-014c, N-020
VBS-018e	The VBS shall continually issue Communication fault alerts to the vehicle operator when the vehicle is in range of an HRI and HRI Geometry messages and/or HRI Activation Status messages are not being received	N-014c, N-020
VBS-018f	The number of messages per second received used to calculate the issuing of a Position Prevalence fault shall be a user configurable parameter.	N-020

Table 19 VBS Requirements (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
VBS-018g	The number of messages per second received used to calculate the issuing a HRI Activation Status Prevalence fault shall be a user configurable parameter.	N-020
VBS-019	Fault alerts shall supersede all other annunciations.	N-002, N-020
VBS-020	Warnings shall supersede inform alerts.	N-002, N-020
VBS-022	The VBS shall be capable of receiving messages sent by the RBS within 50 ms.	N-026
VBS-023	The VBS shall be capable of processing received data within 85 ms.	N-026
VBS-024	The VBS shall know the position of the GNSS antenna relative to the front of the vehicle and the rear of the vehicle.	N-007
VBS-025	The VBS shall be considered within the HRI Approach Zone whenever the current positional information while accounting for all uncertainties falls within the boundaries of an ingress lane, based on the current HRI Geometry.	N-007, N-008, N-014c
VBS-026	The VBS shall be considered within the HRI Hazard Zone whenever the current positional information while accounting for all uncertainties falls within the boundaries between all diametrically opposite lanes that also contains the geospatial location of the HRI, based on the current HRI Geometry.	N-007, N-008, N-014c
VBS-027	The RCVW VBS shall be designed to account for operation in all weather, road surface and visibility conditions.	N-001,N-002, N-006

Source: Battelle

RBS

Table 20 provides RBS requirements specific to this SRS.

Table 20. RBS Requirements

Number	Requirement	ConOps Stakeholder Needs Reference
RBS-001	The RBS shall interoperate with current infrastructure safety systems (e.g. traffic control and train detection devices) in accordance with NEMA TS 2-2021 v03.08.	N-012a
RBS-002a	The RBS shall operate using 60 Hz 115VAC power as the primary power source.	
RBS-002b	The RBS shall be capable of determining HRI activation status using the DC voltage-based preemption signal from the HRI Controller and, indirectly, from an IEEE 1570-compliant serial device that has been interfaced to the HRI Controller, when present.	N-012b
RBS-003	All roadside-based subsystem messages shall contain a header segment that is compliant with the V2X Hub Reference Implementation platform.	N-013b
RBS-003a	All RBS messages shall contain a payload segment containing all required information as an encoded sequence of bytes.	N-013b
RBS-004	The RBS shall broadcast the HRI Activation Status message to both the VBS and CBS 10 times per second during operation.	N-008, N-014b
RBS-004a	The HRI State message shall uniquely identify the grade crossing it pertains to	N-016b
RBS-004b	The HRI State message shall indicate the present state of the preemption signal.	N-015, N-016b
RBS-005	The HRI State message shall indicate "active" whenever the detection system is off-line or disconnected.	N-015, N019a
RBS-005a	When the RBS is connected to an IEEE-1570 compatible device and the Heartbeat signal is lost, the RBS shall cease sending HRI State Messages.	N-015, N019

Table 20. RBS Requirements Table 20. RBS **(Continued)**

Number	Requirement	ConOps Stakeholder Needs Reference
RBS-007	The RBS shall broadcast the HRI Geometry to both the VBS and CBS once per second during operation.	N-014b,
RBS-007a	The HRI Geometry message shall uniquely identify the grade crossing it pertains to.	N-016b
RBS-007b	The HRI Geometry message shall provide the geospatial location of the HRI.	N-016b
RBS-007c	The HRI Geometry message shall provide the geospatial location and geometry of all lanes approaching to (ingress) and leading away from (egress) the HRI.	N-016b
RBS-010	The RBS shall execute periodic BIST to determine the functional state of critical components.	N-020, N-021
RBS-011	The RBS shall employ methods to prevent unauthorized physical and cyber access.	N-023, N-025
RBS-012	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.	N-025
RBS-013	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.	N-026
RBS-016	The RBS shall identify and log system failures to the extent that it is practicable.	N-021
RBS-017	The RBS shall broadcast system diagnostics data to the CBS at least once per second during operation.	N-021
RBS-017a	The RBS Diagnostic message shall uniquely identify the HRI it pertains to.	N-021
RBS-17b	The RBS Diagnostic message shall report the current broadcast rate of the HRI Geometry messages.	N-021
RBS-017c	The RBS Diagnostic message shall report the current broadcast rate of the HRI State messages.	N-021

Table 20. RBS Requirements Table 20. RBS **(Continued)**

Number	Requirement	ConOps Stakeholder Needs Reference
RBS-017d	The RBS Diagnostic message shall report the current broadcast rate of the RTCM messages.	N-021
RBS-017e	The RBS Diagnostic message shall report the current operational state of all RBS components and overall performance.	N-021
RBS-018	The RBS shall incorporate self-recovering routines to recover from a major system failure associated with firmware/software systems.	N-021
RBS-019	Application and system logs will be timestamped using an internally consistent mechanism (e.g., GPS or UTC time) and maintained at least until reported through the RBS Diagnostic message.	N-013c
RBS-020	The RBS shall not interfere with any HRI infrastructure subsystems.	N-012a
RBS-021	The RBS shall be capable of receiving HRI message packets across an IEEE 1570-compliant serial communication interface in less than 250 ms conforming to the IEEE-1570 standard.	N-012b
RBS-022	The RBS shall broadcast Radio Technical Commission for Maritime Services (RTCM) correction messages to the VBS at the same rate it receives them, but not more than once per second.	N-007
RBS-022a	The RBS shall be able to produce RTCM messages directly through the use of a local base station..	N-007
RBS-022b	The RBS shall be able to receive, and relay RTCM messages upon receiving them from the CBS.	N-007

Source: Battelle

CBS

Table 21 provides RBS requirements specific to this SRS.

Table 21.CBS Requirements

Number	Requirement	ConOps Stakeholder Needs Reference
CBS-001	The CBS shall maintain 99.99% cloud service availability when the communications link is healthy.	N-006,N-013d, N-013e, N-021, N-030
CBS-002	The CBS shall prevent unauthorized cyber access.	N-024, N-025
CBS-003	The CBS shall employ methods to ensure incoming data is from an authorized RCVW RBS.	N-024, N-025
CBS-004	The CBS shall implement methods for Cloud based data storage.	N-008, N-018b
CBS-005	All HRI/RBS related information stored within the CBS shall be available for querying when requested by an authorized user	N-008, N-018b
CBS-006	The CBS shall be capable to store HRI related attributes following the guidance of the FRA Data Dictionary for External Use Grade Crossing Inventory System (GCIS)	N-016b,N-008, N-018b
CBS-007	The CBS shall be capable of storing IEEE-1570 Message Type 4904 data elements to the extent they can be obtained.	N-016b,N-008, N-018b
CBS-008	Each data entry stored in the CBS shall be linked to a unique HRI ID.	N-016b,N-008, N-018b
CBS-009	Each HRI ID stored in the CBS shall be linked to a Latitude and longitude attribute	N-016b,N-008, N-018b
CBS-010	Each HRI ID stored in the CBS shall be linked to an attribute indicating if an RBS is present	N-008,N-009

Table 21.CBS Requirements**(Continued)**

Number	Requirement	ConOps Stakeholder Needs Reference
CBS-011	The CBS shall be capable of storing HRI geometry (MAP) for all HRIs linked to an RBS	N-016b,N-008, N-018b
CBS-012	The CBS shall be capable of storing RBS Diagnostic information for HRI's linked to an RBS.	N-016b,N-008, N-018b
CBS-013	The RBS diagnostic information shall indicate the operational status of the data connection between the CBS and RBS	N-13d, N-016b,N-008, N-018b
CBS-014	The RBS diagnostic information shall indicate the radio transmission rates for messages transmitted between the RBS and VBS	N-014b, N-016b,N-008, N-018b
CBS-015	The RBS diagnostic information shall indicate the operational status of the RBS components and overall RBS software modules.	N-021
CBS-016	The CBS shall be capable of storing the HRI activation status for all HRIs linked to an RBS	N-008
CBS-017	Each HRI ID linked to an existing RBS shall have a URL where a HRI Activation Status change shall be reported	N-016b,N-008,N-030
CBS-018	When the CBS receives HRI Activation Status from an HRI linked to an RBS indicating a state change, the CBS shall write a message to the HRI's linked URL with the received state change information	N-016b, N-018
CBS-019	When explicitly queried, the CBS shall be capable of reporting an array of known RCVW RBS equipped HRI identifiers contained within the boundaries of a specified location and radius.	N-011
CBS-020	The CBS shall be capable of maintaining a continuous connection to a Network Transport of RTCM via Internet Protocol (NTRIP) caster for each of the known RBS locations	N-007,N-030

Table 21.CBS Requirements**(Continued)**

Number	Requirement	ConOps Stakeholder Needs Reference
CBS-021	The CBS shall be capable of sending RTCM correction messages to the corresponding RBS within 2 seconds of reception of RTCM information from an NTRIP caster	N-013c, N-008
CBS-022	The CBS shall receive RBS messages within 0.5 second of being sent	N-013c,N-016b
CBS-023	The CBS shall log RBS messages and the corresponding CBS event messages within 5 seconds of being received	N-013c, N-016b
CBS-024	The CBS shall retain a log of RBS messages and corresponding CBS event messages.	

PUR

Table 22 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 22.

Table 22. Production Unit Requirements

Number	Requirement	ConOps Stakeholder Needs Reference
PUR-1	RBS functional modules shall report status within 0.2 seconds of a request by the RBS integrity monitor. The RBS integrity monitor shall transition the RBS to Failure Mode when two consecutive requests have not been acknowledged.	
PUR-2	The RBS RSU radio transmitter/antenna(s) shall provide mission-effective signal strength within the safe-stopping distance zones of an HRI.	N-009, N-011, N-014a
PUR-3	The RBS shall report to a central maintenance facility when the signal strength of its RSU Radio Frequency (RF) transmitter is less than its specified minimum.	N-014a, N-021, N-021
PUR-4	The BIST shall detect ≥ 95% of equipment related failures.	N-020, N-021
PUR-5	The RBS false alarm rate shall not exceed 1%.	N-019a
PUR-6	The RBS failure to warn rate shall not exceed 1%.	N-019b
PUR-7	The equipment and system design shall include provisions to minimize the probability of wrong side failures.	N-019b
PUR-8	The validity of software routines shall be verified using stored test data once per second.	N-020, N-021
PUR-9	Software modification shall require an Administrator Level password to prevent unauthorized modifications.	N-025
PUR-10	Future upgrades in VBS software shall be compatible with existing RBS applications. Future upgrades in RBS applications will be compatible with VBS applications.	N-028

Table 22. Production Unit Requirements (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
PUR-11	The RBS shall report unauthorized access to the RBS shelter to a central maintenance facility via an industry standard wireless network.	N-024
PUR-12	The MTBF of the RBS shall not be less than 50,000 hours.	N-030
PUR-13	The MTTR of the RBS shall not exceed one hour.	N-030
PUR-14	The Availability of the RBS shall not be less than 0.9999, assuming a five-hour mean time to restore service.	N-030
PUR-15	The RBS manufacturer shall commit to supporting the RBS functional components for a minimum of twenty years. Included in the support is providing replacement parts, or form, fit, and function equivalents.	N-029
PUR-16	The RBS manufacturer shall demonstrate that compliance with Configuration Management Plans is standard operating procedure.	N-033
PUR-17	The RBS manufacturer shall establish, unless already in existence, Reliability and Maintainability Improvement programs for the RBS.	N-029, N-033
PUR-20	The RBS shall conduct self-diagnostic testing diagnosis and report status and/or failure to a centralized control center.	N-020, N-021
PUR-21	Application and system logs (for example messages received from VBS OBUs regarding RBS RSUs (in the VBS's data base) 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.	N-020, N-021
PUR-22	All RBS components shall meet an operating temperature range of: -34ºC to 74ºC.	N-031
PUR-23	All RBS components shall meet a storage temperature range of: -45ºC to 85ºC.	N-031
PUR-24	All RBS components shall meet a relative humidity range of 95% condensing over the temperature range +4.4ºC to 43.3ºC.	N-031
PUR-25	Rain: Exposed components of the RBS, 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.	N-031

Table 22. Production Unit Requirements (Continued)

Number	Requirement	ConOps Stakeholder Needs Reference
PUR-26	Salt fog: Exposed components of the RBS, 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.	N-031
PUR-27	Wind: The RBS RSU and antenna(s) mounting bracket(s) shall be able to withstand winds up to 150 miles per hour per AASHTO Special Wind Regions Specification.B19.	N-031
PUR-28	Operating shock and vibration: The RBS 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.)	N-031
PUR-29	Transportation shock and vibration (RBS components packaged for shipment): RBS 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.)	N-031
PUR-30	Electromagnetic susceptibility: All RBS components shall be immune to Radio Frequency (RF) Electromagnetic Interference (EMI) per SAE J1113.	N-031
PUR-31	Electrostatic Discharge RBS: The RBS 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.	N-031
PUR-32	Altitude: All RBS components shall remain operational from -60 to 3600 meters, referenced to mean sea level.	N-031

Source: Battelle

Appendix A - List of Acronyms/Initialisms

ATMS	Advanced Traffic Management System
BCN	Backhaul Communication Network
BIST	Built In Self-Test
CCM	Cloud Communications Module
CBS	Cloud-Based Subsystem
CFR	Code of Federal Regulations
CIM	Cloud Ingest Module
ConOps	Concept of Operations
CORS	Continually Operated Reference Station
CV	Connected Vehicle
C-V2X	Connected Vehicle to Everything
DVI	Driver Vehicle Interface
EMI	Electromagnetic Interference
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
GNSS	Global Navigation Satellite System
GNGSA	Dilution of Precision and Active Satellite Information
GPGGA	Global Positioning System Fix Data
GPGSV	Global Positioning System Satellites in View
GPRMC	Global Positioning Recommended Minimum
GPZDA	Coordinated Universal Time and Date Information
GPS	Global Positioning System
HEM	HRI Event Manager
HCDF	HRI Configuration Data File
HRI	Highway Rail Intersection
Hz	Hertz
ID	Identification or Identifier
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
MDT	Maintenance Data Terminal
MIL-STD	Military Standard
MTBF	Mean Time Between Failures
MTR	Mean Time to Respond

MTTR	Mean Time To Repair
NEMA	National Electrical Manufacturers Association
NTIA	National Telecommunications and Information Administration
NTRIP	Network Transport of RTCM via Internet of RTCM via Internet Protocol
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
PUR	Production Unit Requirement
RBS	Roadside-Based Subsystem
RCM	Roadside Communications Module
RCVW	Rail Crossing Violation Warning
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
SAE	SAE International[7]
SRS	System Requirements Specifications
TCP	Transmission Control Protocol
TMC	Traffic Management Center
US DOT	United States Department of Transportation
URL	Universal Resource Locator
UTC	Coordinated Universal Time
VAC	Volts Alternating Current
VBS	Vehicle Based Subsystem
V2X	Vehicle to Everything
WAVE	Wireless Access in Vehicular Environments

[7] Formerly known as Society of Automotive Engineers

Appendix B – Glossary of Terms

Connected Vehicle to Everything (C-V2X): standard Cellular V2X uses 3rd Generation Partnership Project (3GPP) standardized 4G LTE or 5G mobile cellular connectivity to exchange messages between vehicles, pedestrians, and wayside traffic control devices such as traffic signals. It commonly uses the 5.9 GHz frequency band. It was developed to replace Dedicated Short Range Communications ,commonly referred to as DSRC in the United States and Cooperative Intelligent Transportation Systems (C-ITS) in Europe.

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 RCVW should have been issued but was not. A false positive is a situation where an RCVW was unnecessarily issued.

Geospatial Database: A database with geospatial information about HRIs. The database contains information such as the HRI IDs for all RCVW RBS equipped HRIs 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 consists of 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.

RBS: Consists of an RSU and an Integrated Vehicle-to-Infrastructure computing platform.

Roadside Unit: A component of the RBS 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: Consists of 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 WAVE radios.

Violation: A violation condition may be detected or predicted by the RCVW VBS 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 – Potential ITS Radio Broadcast 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
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

Appendix D – Potential Cloud Based Scenarios

The CBS will provide the necessary information for a third-party subscriber to design and develop different applications based on their specific needs. The following are a few examples of how third-party subscribers may leverage the CBS information. These use cases are for general knowledge and outside the scope of this project. No formal requirements were developed for these scenarios within the RCVW project.

CBS Scenario 1: Commercial Vehicle Dispatching system; HRI Protection System is Active or Becomes Active

The following scenario describes the use of the CBS-available information by a commercial vehicle dispatching system. In this scenario, the dispatching system creates and assigns a route to one of its fleet vehicles. An RCVW equipped HRI is within the designated route. The dispatching system receives information from the CBS on the activation of the protective warning devices of the HRI in route at a site that, historically, is often active for extended periods. As a result, the dispatcher creates an alternate route and provides it to the fleet vehicle.

1. A commercial dispatcher provides a route to one of its fleet vehicles. The route contains an RBS RCVW equipped HRI based on information retrieved from the CBS database.
2. A train is approaching the HRI, and the protective warning device activate
3. The dispatcher receives real-time information on the activation status of the HRI allowing the dispatcher the opportunity to broadcast to the fleet vehicle an alternate route in case of a potential traffic disruption.

CBS Scenario 2: Commercial Vehicle Dispatching system; Low Ground Clearance

The following scenario describes the use of the CBS available information by a commercial vehicle dispatching system. In this scenario, the provider of the dispatching system is subscribed to the CBS and periodically queries the system to retrieve and store location and attribute information of HRIs which will be used during its vehicle routing functions.
During the process of creating a route to one of its fleet vehicles it detects that, based from the CBS historical data, an HRI with low ground clearance is within the designated route. The dispatching system detects this as a potential hazard and creates an alternate route and provides it to the fleet vehicle

1. A commercial dispatcher generates a route for one of its fleet vehicles.
2. The dispatching system generates an alert indicating that the route contains an HRI that has the attribute of Low Ground Clearance based on information retrieved from the RCVW CBS database.
3. The dispatcher proceeds to generate an alternative route and provides it to the fleet vehicle.

CBS Scenario 4: Traffic Management Center

The following scenario describes the use of the CBS available information by a Traffic Management Center (TMC). In this scenario, the CBS is monitoring the status of the HRIs via timely information from the CBS. As an HRI protective warning devices become active, a notice is provided to the advance transportation management system (ATMS) at the TMC and coordinates with nearby intersections to prevent traffic congestion in the area as well as communicates the HRI activation to 511 traffic advisory systems.

1. RBS RCVW equipped HRIs are within the monitoring area of a TMC. The TMC is subscribed to the RCVW CBS database service.
2. The TMC receives information regarding the activation status of the HRI protection systems.
3. The TMC's ATMS uses this information to coordinate nearby traffic signals timing to optimize operational objectives and minimize overall delays.
4. The information is then relayed to a 511-traffic advisory system for public dissemination.
5. Once the protective warning devices deactivate, the ATMS receives this information and coordinates the traffic signal timings accordingly.
6. The information on the 511 traffic advisory is updated as well.

Other CBS Scenarios.

There following are a summary of other scenarios where the CBS information could be useful.

1. Based on information from the CBS, the TMC detects the HRI protection devices have been activated for a long period of time and enables a live video feed to assess the situation.
2. The TMC receives information regarding a degradation in functionality of a monitored HRI based on the diagnostic information provided by the RBS expediting the dispatch of maintenance crews in the event of degraded performance
3. An RBS is installed in *passive* HRIs along with an industry approved train detection mechanism allowing the broadcast of the train presence regardless of the existence of HRI Protection Devices.
4. The RCVW CBS can serve as a depository of HRI information (see list below) available to authorized subscribers:
    a. HRI Attributes
    b. Historical Train Traffic
    c. Historical HRI incidents

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