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

Appendix B to RCVW – Phase II Final Report

Field Test & Evaluation Report

Source: John A. Volpe National Transportation Systems Center

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14. ABSTRACT
This Field Test Report and Evaluation document describes the test procedures, findings, and results obtained during the final field test of the RCVW system conducted at the Transportation Research Center Facilities located at East Liberty, OH.

15. SUBJECT TERMS
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Revision History

Revision	Date	Change Description	Affected Sections/Pages
A	12/08/20	Initial Draft	All
B	3/05/2021	Addressed Comments	All
C	3/22/2021	Addressed Comments	Throughout document
D	4/14/2021	Addressed Comments	Throughout document
E	5/02/2021	Addressed Comments	Throughout document
F	5/17/2021	Addressed Comments	Table 1, GNSS Module Comparative Analysis section

Introduction

The Rail Crossing Violation Warning (RCVW) Phase II builds upon prior proof-of-concept work conducted for the Federal Railroad Administration and Federal Highway Administration's Intelligent Transportations System Joint Program Office (ITS-JPO). Phase 1 of this project demonstrated a vehicle-to-infrastructure (V2I)-based technology intended for use at highway railroad intersections (HRIs) equipped with active warning devices. When a connected vehicle (CV) with RCVW is approaching an active HRI (i.e., an HRI for which the HRI signal controller is receiving a preemption signal) the system warns the driver if the Vehicle-Based Subsystem (VBS) predicts the driver is not taking sufficient action to prevent a violation. The system also warns the driver if the On-Board Unit (OBU) is not receiving a broadcast from the Roadside-Based Subsystem (RBS) being approached and if there is any degradation in the Global Positioning System (GPS) signal. Additionally, drivers of CVs are warned if they are stopped in an HRI that is in Active status.

Phase II of this project involves making refinements to RCVW software and hardware to achieve improved performance and enhanced functionality. Revisions to the RCVW design include:

- Changes to make RCVW compatible with the IEEE 1570 serial communications signal preemption message for the RBS
- Utilization of key vehicle status inputs from the Controller Area Network (CAN) Bus communication for the VBS
- Improved RCVW performance through additional vehicle-based position solutions
- RCVW design, software, and hardware are updated to meet current connected vehicle standards, such as SAE J2735-2016, IEEE 1609.2, 1609.3 and 1609.4; IEEE 802.11p-2016; and Roadside Unit (RSU) v4.1
- The driver-vehicle interface (DVI) of the RCVW VBS is also revised based on a human factors study

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.

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

The safety application, tested by Field Test & Evaluation (FT&E) test cases described herein, applies to freight, intercity-passenger, and commuter railroads with active crossing protection systems. The system provides a means for drivers of roadway-vehicles on approach to an HRI to be warned of a predicted violation when the HRI is active.

Document Organization

This document consists of the following chapters and content.

Referenced Documents identifies the external documentation referenced within this document.

Summary of RCVW Field Test and Evaluation Approach Results provides an overview of the overall results of the FT&E activities.

Summary of Detected Issues and Anomalies and Potential Refinement describes the issues encountered during FT&E activities and the analysis being conducted to understand it.

Detailed RCVW Field Test & Evaluation Results presents performance results and notes for each test case used to demonstrate the functionality and performance of the RCVW system.

Appendix A. RCVW Requirements Traceability Matrix identifies the test cases wherein each requirement is verified.

Audience for the Document

The intended audiences for this document are developers and those responsible for deploying technology and systems for rail safety and CV systems.

Testing Scope

Document Identification

This document describes the FT&E test cases used to confirm the system requirements specified for the RCVW Phase II system. It presents the results and findings as well as the performance of the system during this testing phase. It details the methodology followed to verify and demonstrate that the RCVW system has the functionality and performance capabilities necessary to deliver the features described in the RCVW Concept of Operations (ConOps) document [1] and that the system meets the functional and performance requirements described in the RCVW System Requirements Specification document [2]. The design of the RCVW system is described in the RCVW Architecture and Design Specifications document [3].

Participation

All functionality tested, as described within this document, was developed by Battelle, with assistance and support from Transportation Research Center, Inc. (TRC), Rio Grande Pacific Technology (RIOTECH), and Honda Research & Development Americas (HRA).

Except where noted, results described within this document were based on testing executed by Battelle and RIOTECH at the TRC's Smart Center Test track in East Liberty, OH, on October 28–30, 2020.

Prior to test execution, Battelle and TRC staff installed and integrated Battelle RCVW and RIOTECH equipment at the TRC Smart Center test track and test vehicles. The RCVW RBS (see Roadside-based Subsystem Hardware) was housed within TRCs existing traffic signal cabinet located at the Smart Center Test track (outlined by the red-colored rectangle in Figure 1). RIOTECH provided an IEEE 1570 compatible communication system to generate the train-detection preemption messages. This device follows the IEEE 1570 standard for the interface between a rail subsystem and a highway subsystem at an HRI. RIOTECH provided a test rack which contained the equipment needed to activate a set of flashers and the interface to a Loop detector processor card for the purpose of activating and deactivating the train-detection preemption signal as a vehicle drives over a presence detection loop (outlined by the yellow-colored rectangle in Figure 1). A Tp-link TL-WR802N Nano Router was connected to the RCVW's Central Processing Unit (CPU) to be used as an ethernet bridge (outlined by the blue-colored rectangle in Figure 1). The Nano Router connected wirelessly to a Verizon MiFi 6620L 4 g Jetpack internet hotspot. This configuration allowed remote connectivity to the RCVW system by the Battelle team which was used to observe system performance and troubleshoot any issues remotely.

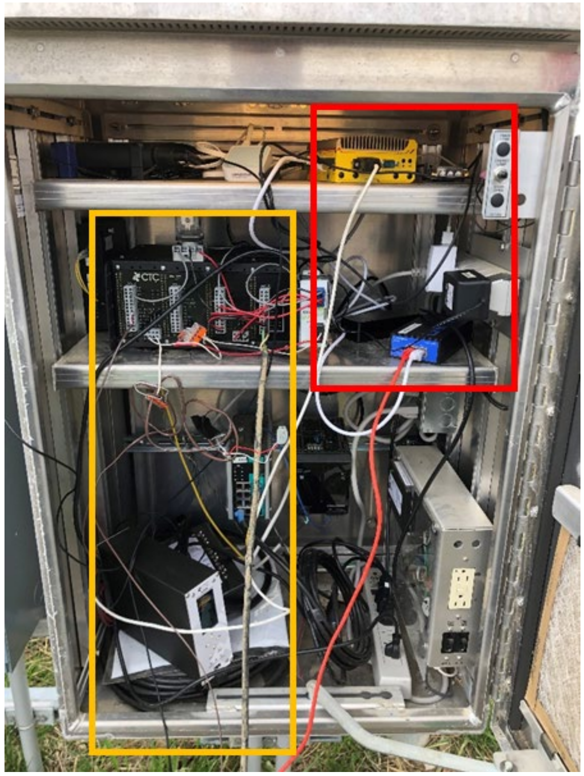


Figure 1. Roadside Equipment

RIOTECH provided a standard-height rail crossing flashing light and crossbuck sign which was positioned at the stop bar location of the HRI and directed toward the approach vehicle (outlined by the red-colored rectangle in Figure 2). Battelle mounted the RBS Dedicated Short Range Communication (DSRC) radio on a portable pole located adjacent to the HRI (outlined by the yellow-colored rectangle in Figure 2). A Real-Time Kinematic (RTK) base station antenna was positioned on top of a tripod away from the cabinet and any obstruction (outlined by the blue-colored rectangle in Figure 2).

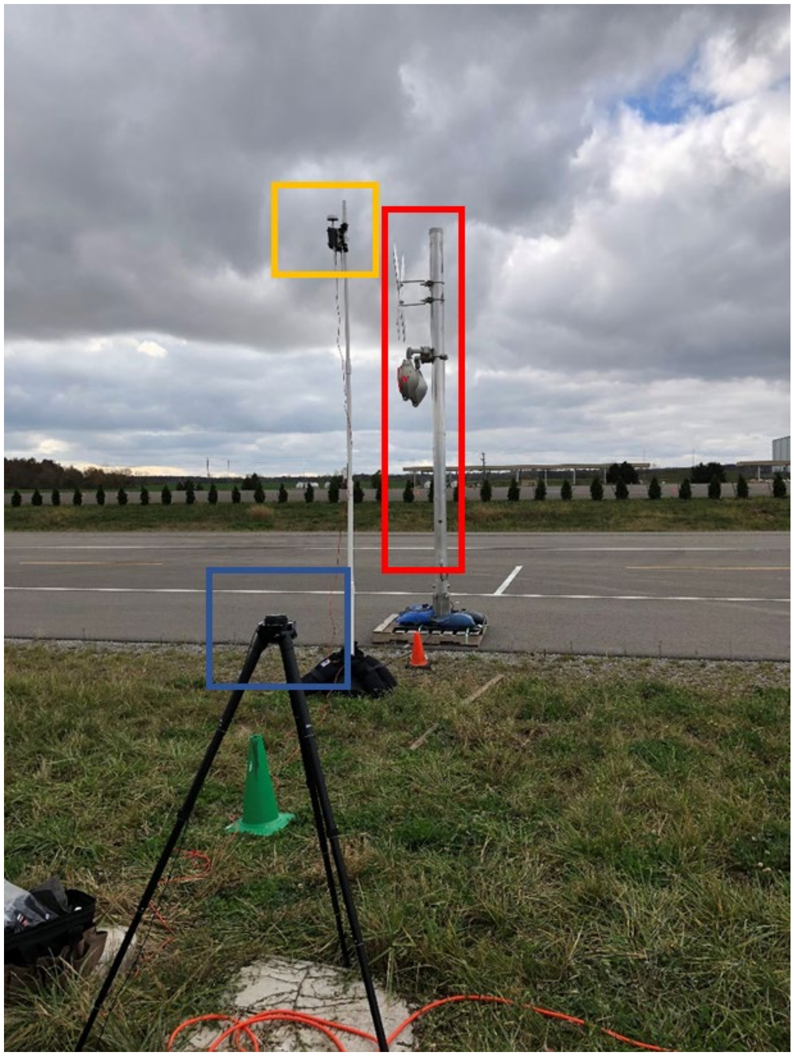


Figure 2. Rail Crossing Crossbuck Sign and Flashing Lights Along with RBS Radio

A 10 percent graded track course located a few miles away from TRC's Smart Center test track was used to test the functionality of the system on a graded road. The roadside equipment along with a traffic signal cabinet was transported to this area and mounted prior to the start of the test. For this test, a power generator was provided by TRC which powered the roadside equipment.

The vehicles used for this field test were provided by TRC and HRA. An Acura MDX 2017, SH-AWD was provided by HRA and was used for the light vehicle tests. See Figure 3.

Figure 3. Acura MDX 2017 SH-AWD

TRC provided a 2017 Volvo Truck VHD which was used for the Heavy Truck tests. See Figure 4.

Figure 4. 2017 Volvo Truck VHD

Battelle with the support of TRC staff equipped both vehicles with the VBS equipment (see Vehicle-Based Subsystem Hardware).

Figure 5. RCVW/Test Equipment on Light Vehicle

Figure 5 shows the RCVW's Driver Vehicle Interface (DVI) (outlined by the red-colored rectangle) alongside TRC's test equipment (outlined by the blue-colored rectangles). The rest of the RCVW VBS components were located in the back of the car (not seen in the figure).

Figure 6. RCVW/Test Equipment on Heavy Vehicle

Figure 6 shows the RCVW's DVI (outlined by the red-colored rectangle) alongside TRC's test equipment (outlined by the blue-colored rectangles). The rest of the RCVW VBS components were located by the passenger-seat's floor area (not seen in the figure).

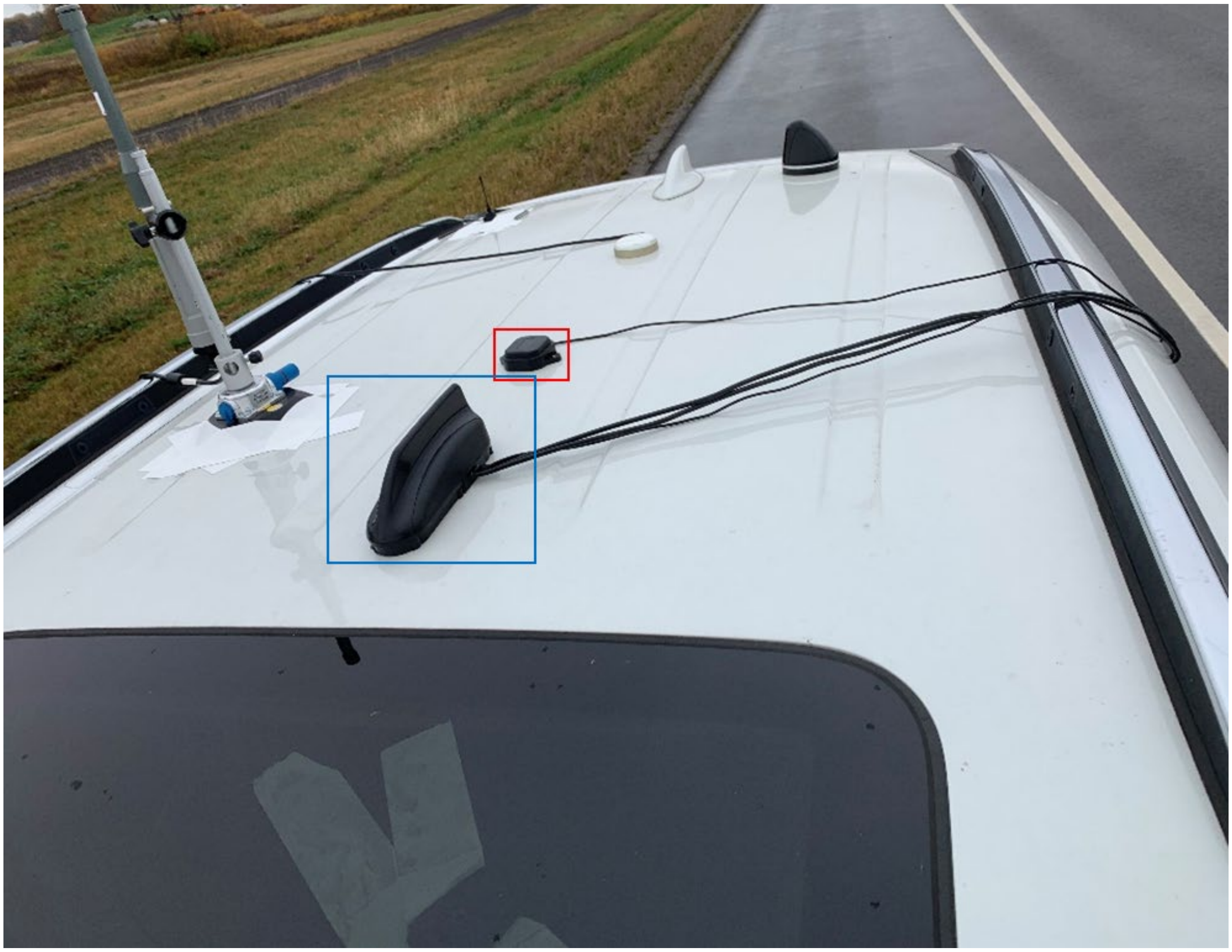


Figure 7. Placement of Antennas on Light Vehicle

Figure 7 shows the RCVW's antennas as placed on the roof of the light vehicle. The DSRC radio and GPS antennas are contained within the unit shown in the blue box. The antenna within the red box is the GNSS antenna connected to the RCVW's GNSS module. The rest of the antennas in the image are part of TRCs test equipment.

Figure 8. Placement of Antennas on Heavy Truck

Figure 8 shows the RCVWs antennas as placed on the roof of the heavy truck. In this case, the GNSS antenna that connects to the RCVW module was placed on top of a rack in an attempt to elevate it from the roof and away from the truck's overhang. The unit that contains the DSRC and GPS antennas was placed at the center of the cabin's roof. The rest of the antennas in the image are part of TRC's test equipment.

As with the RBS, and to allow for remote connectivity to the VBS, a Tp-link TL-WR802N Nano Router was placed inside of both vehicles and was connected to the RCVW's CPU. The router connected wirelessly to a Verizon MiFi 6620L 4 g Jetpack internet hotspot.

Test Execution was conducted by six team members: three from Battelle and three from TRC. RIOTECH's Project Manager for Special Projects provided the Battelle team Phone support. Daily reports were relayed via email to the client and client representatives.

One Battelle team member directed the testing, led data reconciliation efforts during and after each test run and coordinated with TRC staff for logistics and support. A second

Battelle team member was responsible for collecting the start and end times for each test run start and ending, notifying the CV driver of the test to be performed, taking notes of any irregularities communicated by the driver and support in reconciliation activities. A third Battelle team member monitored the algorithm operation, remotely accessing both the Light Vehicle and Heavy Vehicle RCVW systems when needed for any technical aspects and resolution of issues.

Two TRC team members were dedicated to operating both vehicles, which typically involved driving the vehicles straight along the approach (except in cases where the vehicle swerved to the right and left of the approach), monitoring and operation of the onboard TRC test equipment (see TRC Testing Equipment) and activating the brakes in the case of a braking robot malfunction.

Prior to the field test efforts, TRC staff marked several locations along the testing field of particular interest:

- The locations of the stop bar (Smart Center and Graded Course)
- Locations where the system should issue an RCVW warning (based on vehicle type and speed). For reference only.
- Locations where the vehicles were expected to come to a full stop (based on vehicle type and speed). For reference only.

At the conclusion of each day of testing, the Battelle team retrieved system log files to analyze the latency and positional accuracy of the system (see DSRC Messaging and Data Processing Latency Requirement Verification). In addition, detailed, notes from each day capturing unexpected or abnormal test results were used to generate a more focused approach for subsequent testing.

RCVW FT&E Test Setup

The following sections describe the layout of equipment and connections used for the RCVW VBS and RBS components.

The RCVW system consists of two physically separate subsystems: a VBS installed in the CVs and an RBS integrated with roadside infrastructure at HRIs. Both subsystems share some common hardware and software components, as well as include unique components. The RCVW system in its entirety includes the following components:

- Computing Platform (CP): The heart of the RCVW system are its CPs. The CPs control the RCVW subsystems. One is located in the VBS and a second in the RBS. The V2I Hub software resides within both CPs.
- DSRC Radios: The VBS and RBS utilize DSRC radios, an OBU and an RSU, to provide low-latency wireless communications.
- Global Navigation Satellite System (GNSS): A multi-band GNSS module with built-in RTK technology resides within the VBS to provide real-time lane-level position data. A similar device resides within the RBS to provide Radio Technical Commission for Maritime Services (RTCM) corrections to be broadcasted via DSRC.

- DVI is the RCVW interface to the connected vehicle driver which provides the RCVW warnings and alerts.

Hardware Overview

Roadside-Based Subsystem Hardware

A hardware block diagram for the RCVW RBS used during field test is shown in Figure 9.

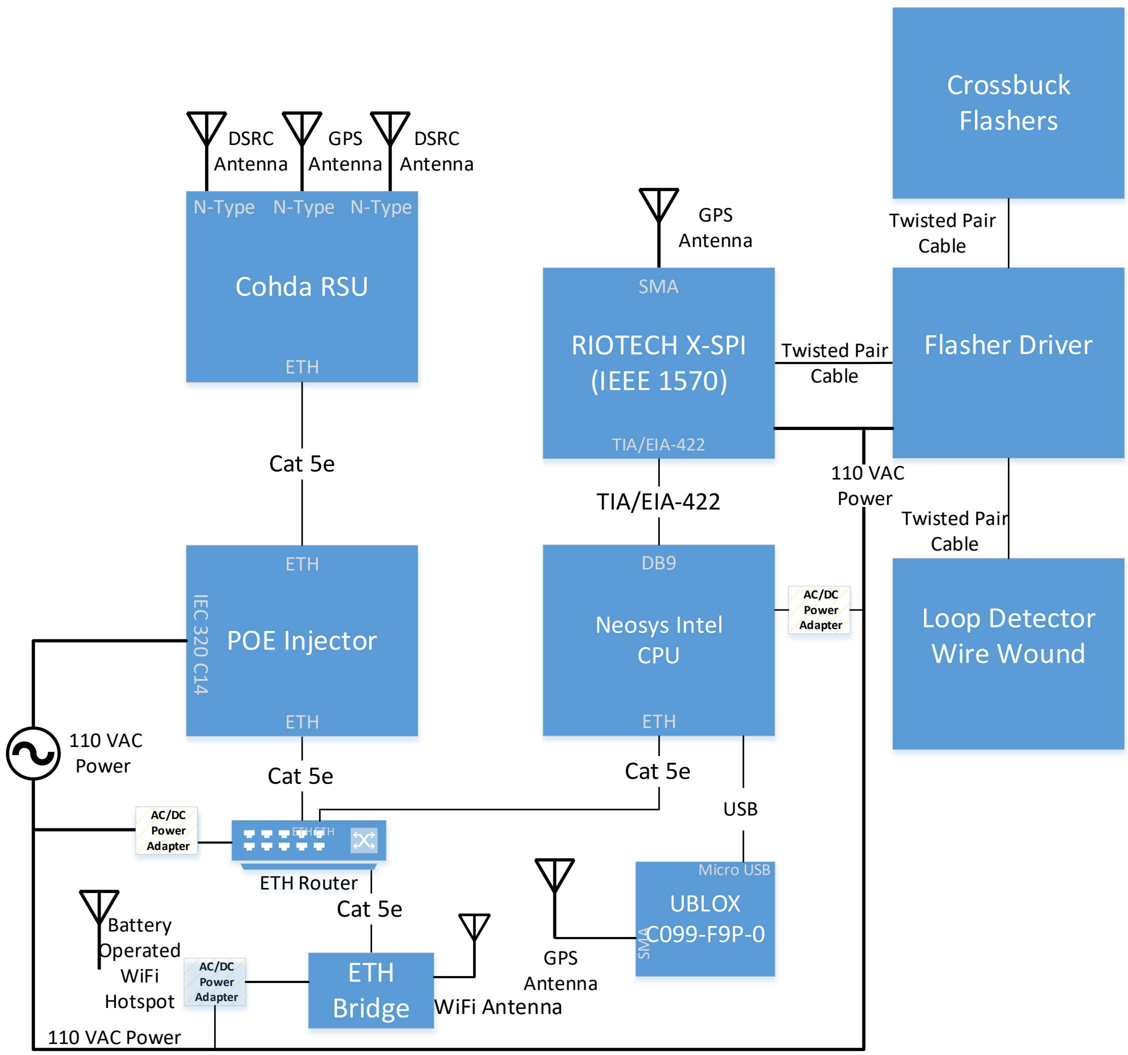


Figure 9. RBS Hardware Used for Field Test

The RCVW RBS produced SAE J2735 MAP Data (MAP) and SPaT messages as well as RTCM messages to support the RCVW VBS algorithms used to provide warnings to the driver. The J2735 MAP file contained the Approach Zone geometry for the mock-equipped HRI, while the J2735 SPaT message communicated the HRI activity status (i.e., whether the warning devices were active). The RTCM messages broadcasted contain real-time details about the GNSS network, as well as perturbations in the ionosphere and troposphere which are to be used by the vehicles onboard GNSS RTK unit to correct the location solution of the vehicle.

RBS Equipment:

- DSRC RSU
  - A Cohda MK5 4.0 RSU
- Power Over Ethernet (POE) injector to supply the RSU with power:
  - Linkysys LACP130
- CPU running the V2I Hub with Message Receiver, MAP, HRI Status, Command, and DSRC Message Manager plugins
  - A Neousys POC-351 VTC with Intel Apollo-Lake ATOM x7-E3950 quad-core processor
- GNSS base station providing RTCM corrections
  - U-blox C099-F9P application board
- IEEE 1570 preemption device
  - RIOTECH X-SPI
- Ethernet router
  - Cisco-Linksys BEFSR81 router
- Wi-Fi hotspot
  - Verizon MIFI 6620L 4 g Jetpack used to enable remote communications to the roadside system
- Tp-link TL-WR802N Nano Router (Ethernet Bridge) to provide remote connectivity
- Flasher Driver
  - The Flasher Driver allows the control of the Flasher and Crossbuck when operated by the loop detector. This equipment is only used for test cases where train preemption is activated/deactivated after the vehicle has entered the approach. It is composed of the following hardware:
    - Reno A&E E-1200 Loop processor card
    - RIOTECH Custom Flasher Driver
    - RIOTECH Custom High Current driver
    - KRP relay (not shown on Figure 9). The KRP relay is physically located on top the flasher driver. It is used in connection to the Loop Detector and switches power to the Flasher once a vehicle is detected by the Loop Detector. Used for test cases where train preemption is activated/deactivated after the vehicle has entered the approach

- Loop detector wire wound
- RIOTECH Constructed Flasher and crossbuck

RBS Connections:

- The Neousys Intel CPU, ethernet router, PoE injector, ethernet bridge, IEEE 1570 Serial interface and flasher controller received power from the power outlet located within the signal controller cabinet.
- DSRC antennas were connected to the RSU
- GPS antennas were connected to the RSU, the RIOTECH X-SPI device and the ZED-F9P RTK GNSS
- U-blox C099-F9P application board RTK GNSS module was connected to the Neousys Intel CPU via a vendor provided USB cable
- Ethernet cables were run and landed as follows:
    - Neousys CPU to the ethernet router
    - PoE injector data /IN port to ethernet router
    - PoE injector P+D / OUT port to the RSU
    - Ethernet bridge to the router
- The IEEE 1570 Serial communication interface connected to the CPU via a TIA/EIA-422 compliant cable.

Vehicle-Based Subsystem Hardware

A hardware block diagram for the RCVW VBS used during field test is shown in Figure 10.

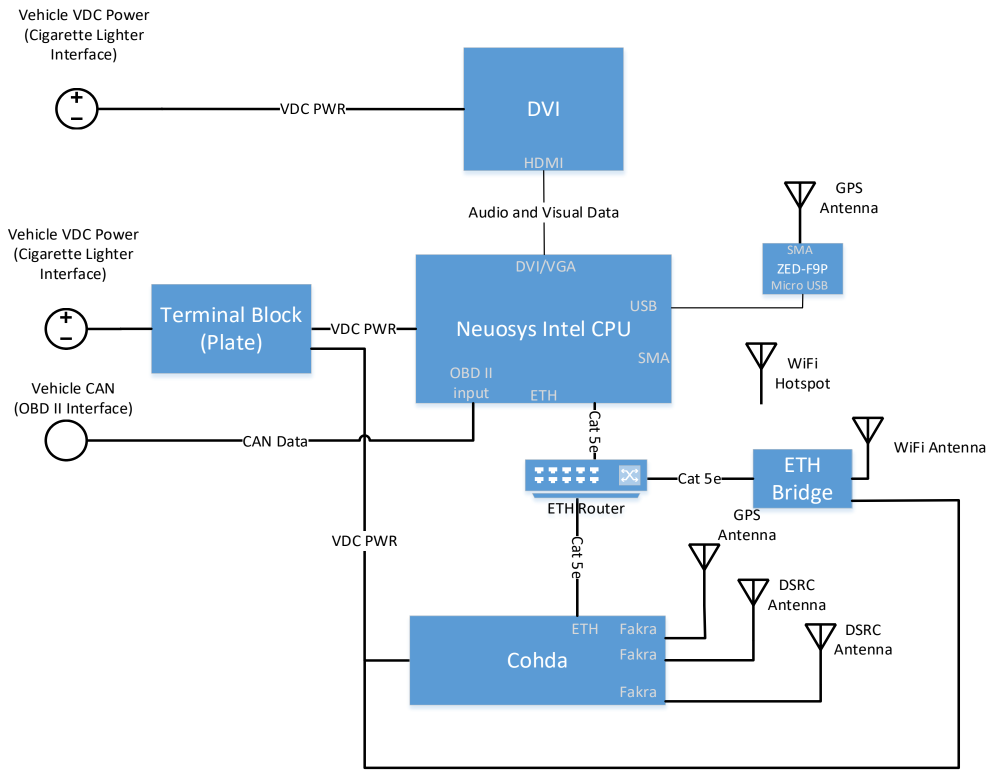


Figure 10. VBS Hardware Used for Field Test

VBS Equipment:

- Neousys Intel CPU running V2I Hub with the Vehicle Interface, Message Receiver, Location, Command, and RCVW plugins
- Cohda MK5 OBU
- Multi-Band, Multi-Constellation RTK GNSS Device
    - U-blox C099-F9P application board
- Ethernet router
    - Cisco-Linksys BEFSR81 router
- Wi-Fi Hotspot
    - MiFi 6620L 4 g Jetpack used to enable remote communications to the VBS system
- Tp-link TL-WR802N Nano Router (Ethernet Bridge) to provide remote connectivity

- External magnet mount antenna for DSRC
- External magnet mount antenna for GNSS
- DVI
- RAM Pod HD vehicle mount to support the DVI
- DVI Power Cable
- Vehicle VDC Power cable
- CAN cable

VBS Connections:

- The DVI was attached to the RAM Pod HD vehicle mount hardware. This hardware is designed to be bolted to the vehicle's passenger seat rail
- The DVI receives power from a cigarette lighter interface
- The Neousys, Cohda MK5 OBU and GNSS device receive power from a cigarette lighter interface
- CAN cable is connected from the On-Board Diagnostics (OBD) II interface to the Neousys Intel CPU
- Antennas are attached to the roof of the vehicle and connected to the Cohda MK5 OBU and GNSS devices
- ZED-F9P RTK GNSS module was connected to the Neousys CPU intel CPU via a vendor provided USB cable
- Cohda MK5 OBU connects to the CPU via an Ethernet cable

TRC Testing Equipment

For validation of the performed test cases, researchers used the following equipment provided and operated by TRC.

- OxTS RT3003 High Accuracy Multi-Axis GNSS aided Inertial Navigation System
- DEWE-43A Data Acquisition System (DAQ)
- SEA Ltd. Breaking and Throttle Robot (BTR)

The SEA Ltd. BTR had a camera focused on the DVI screen analyzing the pixel changes. Once the BTR system detected that an RCVW warning was issued, the system allowed for 2.5 seconds delay before it released the throttle and applied the brakes. The BTR was configured with a variable braking deceleration algorithm. The brake activation delay was programmed to the parameter values the RCVW system has for a driver's perception-reaction time.

The OxTS system was used as a "ground truth" system to compare the RCVW's system vehicle dynamics values. The DAQ System collected the data from the OxTS system and two separate cameras, which recorded a forward view through the windshield and the DVI display. See Figure 11 and Figure 12.

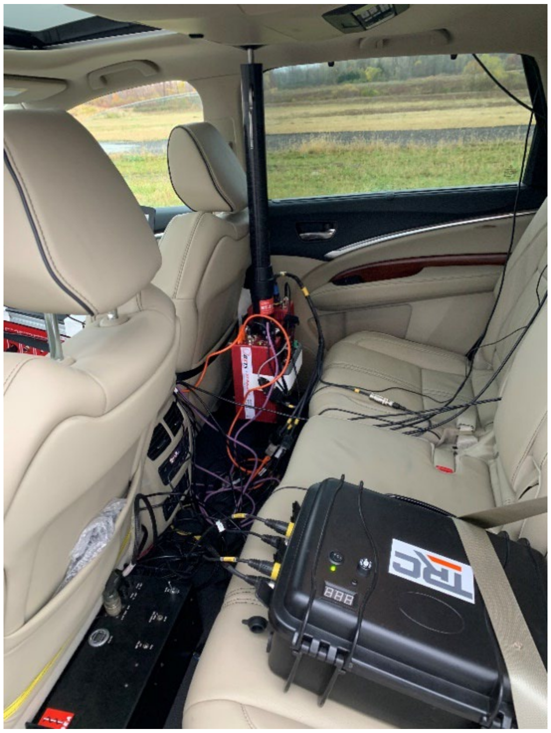


Figure 11. TRC Test Equipment in the Light Vehicle

Figure 12. TRC Test Equipment in the Heavy Truck

Referenced Documents

Referenced Documentation

1. Neumeister, D. (2019). Vehicle-to-Infrastructure Rail Crossing Violation Warning - Concept of Operations. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration, Federal Highway Administration.
2. Polinori, A., Paselsky, B., & Sanchez-Badillo, A. (2020). Vehicle to Infrastructure Rail Crossing Violation Warning - Phase 2. System Requirements Specification. Washington, DC: U.S. Department of Transportation, Federal Railroad Administration.
3. Polinory, A., Baumgardner, G., Paselsky, B., & Sanchez-Badillo, A. (2020). Vehicle-to-Infrastructure Rail Crossing Violation Warning - Phase 2. Architecture and Design Specifications.
4. American Association of State and Highway Transportation Officials. (2018). A Policy on Geometric Design of Highways and Streets. AASHTO.

Summary of RCVW Field Test and Evaluation Approach Results

The objective of the verification testing comprising the RCVW Phase II FT&E Plan was to verify and demonstrate that the RCVW system possesses the functionality and performance necessary to deliver the functions and benefits proposed for the system described in the RCVW Concept of Operations [1]. The intent of FT&E testing is to verify that the RCVW system meets the requirements documented in the System Requirements Specification [2] via controlled field testing of the design specified in the Architecture and Design Specifications document [3].

This chapter begins with a summary of the approach taken in conducting the testing, provides test execution and coordination details, presents a summary of testing performance and concludes with a summary of issues found and resolutions implemented during FT&E testing. The next section presents detailed test summary results and notes.

Approach to Scenario-Based Field Testing

The primary focus of FT&E was to assess the performance of the RCVW system on a subset of the scenario-based test cases performed in BT&E. Table 2 summarizes the scenario-based test cases conducted in the Appendix. These tests were performed in a closed test track solely dedicated for the testing of the RCVW application and the RCVW system was integrated into surrogate infrastructure. All scenario-based tests used a real vehicle driven towards a mock equipped HRI, configured as described above.

A total of 28 scenario-based test cases were performed; 8 consisted of 30 runs, 1 consisted of 7 runs (due to time constraints); 5 fault verification tests were performed once the rest of the cases consisted of three runs each. In addition, an Ad Hoc Stability test was performed in three 10-minute stages which were aimed at assessing the level of nuisance alerting observed under specified challenging circumstances with the vehicle stopped at various locations near/within/beyond the HRI Hazard Zone.

The following parameters applied across all scenario-based test cases:

- Two types of vehicles are referenced in the test cases performed. Type A represents a light passenger vehicle and Type C represents a Heavy Truck.
- The Type A CV was an Acura MDX 2017, SH-AWD with an Anti-Lock Braking System (ABS), while the Type C CV was a Volvo Truck 2017 VHD with an air brake system.
- The approach lane length for both courses (flat and graded) was 1,525 feet. This distance was calculated based on the Decision Sight Distance (for the posted speed limit) to the traditional Warning Sign Placement advising of the presence of an HRI, plus the distance to the HRI of such Warning Sign. For example, for a 55-mph rural road with a Decision Sight Distance of 535 feet and a traditional

Warning Sign Placement of 990 feet (per the Manual on Uniform Traffic Control Devices [MUTCD] Table 2C-4), an approach lane for the vehicle should begin at 535 + 990 = 1,525 feet from the stop bar.

- The initial CV approach speed attained near the start of the Approach Zone and maintained throughout the approach to the point when the RCVW alert varied depending on the type of vehicle and test case. For the majority of Test Cases the vehicle speed for both vehicle types was 50 and 35 mph. For Test Cases 2.2.1L, 2.2.2.6, and 2.4.8 the approach speed was 70 mph. In the case of the Volvo VHD truck, due to the limited amount of roadway in advance of the length of the approach lane, the vehicle was not able to reach the 70 mph for Test Case 2.2.6. For this particular case, the vehicle speed was modified to be 60 mph. The inability to reach the initial approach speed prior to the approach lane entry had no impact on the location at which the RCVW warning was issued or the vehicle response. The RCVW warning was presented closer to the HRI as a result of the decrease in speed.
- All scenario-based test cases involved driving the vehicle straight along the approach except the following
  - Test Cases 2.6.5 and 2.6.6 involved the vehicle driving straight along the approach and swerving one lane width to the right or left (depending on the case) after receiving an RCVW. The purpose of these tests is to verify the “snap to lane” functionality which enables the system to position the vehicle in lane in case of a GPS multipath error. For safety issues, the braking robot was disabled during these test cases.
- All scenario-based test cases began with the HRI in the active state, except the following
  - HRI was specified to become active with the vehicle on approach with less than the full warning distance remaining such as 3/4 warning point, (Test Cases 2.4.9 and 2.4.1), the warning midpoint (Test Cases 2.4.2 and 2.4.7), or the 1/4 warning point (Test Cases 2.4.3a and 2.4.3b).
- A particular scenario (Test Case 2.4.4) began with the HRI in the active state and as the vehicle reaches the midpoint, HRI becomes inactive.

  Note: for cases where HRI state was to change from active to inactive and vice versa, the use of a loop detector was planned. The loop detector was to detect the presence of the CV and activate/deactivate the preemption signal. Weather related issues prevented the use of the loop detector. See Verification of Requirement RBS-21 for details.
- Two deceleration rates were programed into the braking robot for both vehicle types:
  - 3.92 m/s2 (0.4 g) for light vehicle (Type A)
  - 2.67 m/s2 (0.27 g) for heavy truck (Type C)

Note: due to several circumstances (see Braking Robot Deceleration Rate) the braking robot was not able to precisely provide the preprogramed deceleration rate. These variations did not have an impact on system performance.

- Five traffic cones were used along the Approach Zone only for visual reference only while conducting tests.
    - Cone #1: Approach Zone entry
    - Cone #2 and # 3: Expected point of RCVW Activation for CV type A and CV type C travelling at 50 mph (respectively)
    - Cone #4 and #5: Expected vehicle stopping for CV type A and CV type C travelling at 50 mph (respectively)
- Two test track locations were used during field test activities (see Figure 13 and Figure 14)
    - A flat course located at
        - Latitude: 40.313618
        - Longitude: -83.555281
    - A graded course (-10% grade) located at
        - Latitude: 40.322333
        - Longitude: -83.619414

Note: RCVW Activation and Expected Vehicle Stopping Icons in Figure 13 and Figure 14 are for illustration purposes and do not reflect the actual locations of the cones.

Figure 13. Flat Course

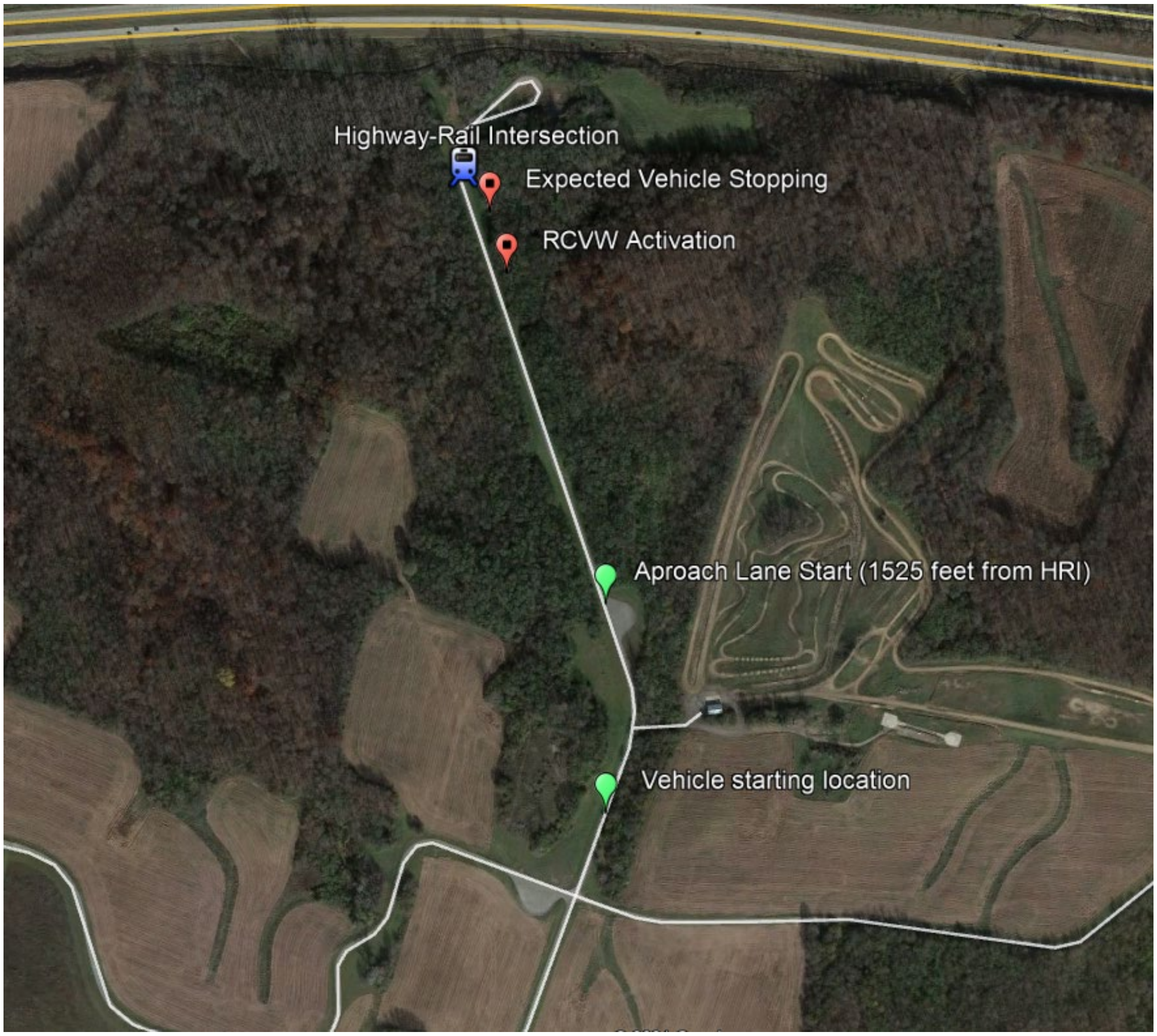


Figure 14. Graded Course

- All tests were performed using an IEEE 1570-compliant serial interface to receive grade crossing status (i.e., the preemption signal)
- Voltage based grade crossing status reception was not performed during this round of testing as it was previously verified during bench test
- The American Association of State Highway and Transportation (AASHTO) Green Book [4] recommends the use of 2.5 seconds perception reaction time. This value reflects observed behavior for the 90th percentile driver
- Different road conditions (wet/dry) were tested during Phase II FT&E.
- Two MAP files were created and used for field testing; one for the Smart Center course (0% grade) and the second one for the Graded Course (-10% grade). Different elevation points from the actual graded course were used for the creation of the MAP, this MAP was then compared to actual logged runs previously performed on site for elevation validation.

- The following default parameters are set into the system (some vary depending on vehicle type). These are all configurable parameters and can be modified according to the system needs. All parameters prefixed with the word “V2” are set specific to the RCVW Phase II implementation. All others are either common (Phase I and Phase II). See Table 1.

Table 1. RCVW System Parameters

Key	Default	Description
Message Expiration	2000	Parameter used to enter the amount of time in milliseconds to wait before issuing a warning indicating that current message data is stale.
Output Interface	0	Parameter used to input the value that corresponds to the type of interface that the application needs to display its messages on. 0=Digital Visual Interface (DVI), 1=Ford SYNC, 2=Android Auto.
Distance to HRI	480	Parameter that indicates the maximum distance (in meters) away from an equipped HRI that a System Fault may be issued due to communication failure. When the VBS is within this distance of the HRI, the system checks for MAP and SPAT expiration timeout, if the GNSS system achieved an RTK fix and if location messages are being received at the configured rate.
HRI Locations	":"{ \"HRIs\": [\n {\"Latitude\":0, \"Longitude\":0, \"HRIName\":\"Hilliard-Davidson\"}\n] }",	This parameter shows the JavaScript Object Notation (JSON) data defining a list of equipped HRI locations loaded into the system.
Extended Intersection	0.1	The percentage to add to the radius of the intersection divided by 100. i.e., in this case the percentage to be added is 10%. So, the value to enter is 10/100 = 0.1
HRI Warning Threshold Speed	1.0	The maximum vehicle speed in meters per second for which the HRI warning will be active if the vehicle is in the HRI and moving. If the vehicle’s speed falls below this threshold, a warning will be issued to the driver.
Use Calculated Deceleration	false	Use calculated deceleration to determine if vehicle will stop before HRI in addition to velocity-based warning calculation.
Log Level	DEBUG	The logging level of the RCVW system.
V2 Antenna Placement X	0.5	Antenna placement X with respect to front left corner of vehicle in meters.
V2 Antenna Placement Y	2.5	Antenna placement Y with respect to front left corner of vehicle in meters.
V2 Antenna Placement Height	1.5	Antenna height with respect to the road surface in meters.
V2 GPS Error	3.12	GPS longitudinal error in meters. The system uses this value directly in the RCVW calculation formula to calculate the issuing of alerts and warnings. This value represents the longitudinal error of the GNSS system. It is a configurable parameter and as such it can be

Key	Default	Description
		modified according to the system and vehicle performance. The default value of 3.12 was selected as a result of preliminary testing to show good system performance.
V2 Reaction Time	2.5	Perception-Reaction time in seconds. AASHTO uses the term "Perception-reaction" time and it represents the time it takes for a road user to 1) realize that action is needed due to a road condition, 2) decide what action to take and 3) start the action.
V2 Communication Latency	0.3	Communication latency in seconds. The system uses this value directly in the RCVW calculation formula to calculate the issuing of alerts and warnings. This parameter accounts for DSRC radio signal communication latencies and IEEE 1570 data package reception latencies (if used). The default value of 0.3 is based upon RCVW system requirements VBS-22 and RBS-21 (see the Appendix) for allowable communication latency.
V2 Application Latency	0.085	Application latency in seconds. The system uses this value directly in the RCVW calculation formula to calculate the issuing of alerts and warnings. It considers the latency of the whole RCVW application for processing data and issuing warnings and alerts. The default value of 0.085 is based upon RCVW system requirement VBS-23 (see the Appendix) for allowable application latency.
V2 Deceleration Car	3.4	Minimum expected controlled deceleration for a car in $\frac{m}{s^2}$
V2 Deceleration Light Truck	2.148	Minimum expected controlled deceleration for a light truck in in $\frac{m}{s^2}$
V2 Deceleration Heavy Truck	2.322	Minimum expected controlled deceleration for a heavy truck in in $\frac{m}{s^2}$
V2 Vehicle Type	1	Vehicle type, 1 = Car, 2 = Light Truck, 3 = Heavy Truck.
V2 Vehicle Length	4.8	The length of the vehicle in meters.
V2 Use Vehicle Based Measurement (VBM) Deceleration	false	Use VBM deceleration to determine if vehicle will stop before HRI in addition to velocity-based warning calculation.
V2 Log SPaT	false	Log SPaT messages at DEBUG level.
V2 Critical Message Expiration	500	The amount of time in milliseconds to wait before issuing a warning that the current critical message data is stale.
V2 Use Config Grade	false	If False, the system will use the grade directly from the receiving MAP. If True, the system will use the V2 Grade configurable variable for grade calculations.

Key	Default	Description
V2 Grade	0	If Parameter V2 Use Config Grade is set to True, this grade value will be used in warning distance calculations. The value is defined as change in height over change in distance.
V2 Check RTK	true	If enabled check location message for RTK fix while in range of HRI. If enabled and the location message does not show an RTK fix, a System Fault is issued.
V2 Check Location Frequency	true	If set to true, the system will check the Location Message reception rate. If the rate of location messages falls below the value of the parameter shown in V2 Minimum Location Frequency, a System Fault message is issued.
V2 Location Frequency Sample Size	30	This parameter is used if V2 Check Location Frequency is set to true. It is the number of location messages to sample to determine frequency.
V2 Minimum Location Frequency	8	This is the minimum allowed average location message frequency in messages per second.
V2 Max Heading Change	45	The maximum allowed heading change in degrees before ignoring the new position.
V2 Max Ignored Positions	7	The maximum number of consecutively ignored positions due to heading change.

In Phase II, the current AASHTO Green Book Stopping Sight Distance formula was used to issue a warning to a vehicle, modified to include additional information unique to the current implementation.

$$D = N + P + 0.278 * V * (T[r] + T[c] + T[a]) + (0.039 * V^2)/(A/g+G) \tag{1}$$

here:

D = distance (m)

N= antenna placement (m)

P = GPS error (m)

V = speed (m/s)

T[r] = reaction time (s), AASHTO 90% rate = 2.5 s

T[c] = communication latency (s)

T[a] = application latency (s)

A = acceleration (m/s^2), AASHTO 90% rate = 3.4 $\frac{m}{s^2}$

G = grade, rise/run (m/m)

g = 9.81 $\frac{m}{s^2}$

For this FT&E task, the Battelle team decided to configure the following latency parameters to both the light vehicle and the heavy truck RCVW systems:

- T[c] = 0.3 seconds
- T[a] = 0.085
- P = 3.12 m

These values were chosen based on the maximum allowed latency according to the RCWV system requirements and were assigned to observe the response of the system. For the case of the GPS error, the value of 3.12 m represents a longitudinal error, it was selected as a result of preliminary testing to show good system performance.

The standard perception-reaction time of 2.5 seconds cover 90 percent of all situations, however the green book also covers situations that are more complex or critical and has guidelines for increasing this time to anywhere from 3 seconds to 9.1 seconds for different environments. A comfortable deceleration rate or of 3.4 m/s^2 also covers 90 percent of all drivers in both dry and wet conditions given current pavement, tire, and vehicle technologies. Considerations have been given to decrease the deceleration rate value for trucks. The deceleration rates used are based on the current Federal Motor Vehicle Safety Standards (FMVSS) 121 and FMVSS 135.

A ratio between the AASHTO guidelines for stopping sight distance and the FMVSS requirement for passenger cars in ideal conditions was calculated and the same ratio was used to generate recommended deceleration values to use for light and heavy trucks.

FMVSS performance requirements for light vehicles:

Stopping distance for 60 mph test speed: ≤230 ft.

Stopped distance for reduced test speed: $S \leq 0.10V + 0.0060V^2$.

$S = (.1 * V) + (.006 * V^2)$

$A = (.039 * V^2) / S$

R(FMVSS) at 60 mph = 0.568, for lower speeds the value is lower

R(AASHTO) = 3.4 / 9.81 = .347

AASHTO recommendation = 0.347 / 0.568 * 100 = 61% of FMVSS requirements

Light (single unit) truck:

FMVSS Performance requirements (worst case): Stopping distance for 60 mph test speed: 335 ft

R(FMVSS) recommendation light truck deceleration = 0.61 * 0.359 * 9.81 = 2.148 $\frac{m}{s^2}$

Heavy (tractor) truck

FMVSS Performance requirements (worst case): Stopping distance for 60 mph test speed: 310 ft

R(FMVSS) at 60 mph = 1.075 * 60^2 / 310 / 32.2 = 0.388, for lower speeds the value is the same or lower

RCVW2 recommended heavy truck deceleration = 0.61 * 0.388 * 9.81 = 2.322 $\frac{m}{s^2}$

These deceleration values are used to calculate warning distance in equation (1) for the different types of vehicles. The breaking robot used during field test does not guarantee that the rate of deceleration configured will be 100 percent accurate for all runs. TRC's experience using the system for different vehicle field tests shown that the deceleration rate is in general lower than what is programmed. To account for this and following TRC's experience with the system, the deceleration rate programmed for the light vehicle was 3.92 $\frac{m}{s^2}$ and 2.67 $\frac{m}{s^2}$ for the heavy truck.

Table 2 summarizes the conditions and inputs for each of the scenario-based test cases executed in FT&E.

Table 2. Distinctive Conditions for the Scenario-Based FT&E Test Cases

Test Case Number	CV Location at Preemption Signal Detection	CV Speed at Approach Entry	Vehicle type*	RCVW State	Vehicle Deceleration Rate**	Reaction Time	Road Conditions	Grade	Vehicle Out of Lane
2.1.1	N/A no preemption	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.2.1e	Start of Approach	35 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.2.1h	Start of Approach	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.2.1l	Start of Approach	70 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.2.3	Start of Approach	50 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Dry	0%	N/A
2.2.5	Start of Approach	35 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Dry	0%	N/A
2.2.6	Start of Approach	70 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Dry	0%	N/A
2.2.7	Start of Approach	35 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Wet	0%	N/A
2.2.8	Start of Approach	50 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Wet	0%	N/A
2.2.9	Start of Approach	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Wet	0%	N/A
2.2.10	Start of Approach	50 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Wet	0%	N/A
2.3.1	Start of Approach	35 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	-10%	N/A
2.4.1	3/4 Point	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.4.2	Midpoint	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.4.3a	Near HRI Hazard Zone	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.4.3b	Near HRI Hazard Zone	50 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Dry	0%	N/A
2.4.4	Start of Approach, then preemption is removed at Midpoint	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.4.7	Midpoint	50 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Dry	0%	N/A
2.4.8	Midpoint	70 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.4.9	3/4 Point	50 mph	Type C	Normal	2.67 m/s^2 (.27 g)	2.5 Seconds	Dry	0%	N/A

Test Case Number	CV Location at Preemption Signal Detection	CV Speed at Approach Entry	Vehicle type*	RCVW State	Vehicle Deceleration Rate**	Reaction Time	Road Conditions	Grade	Vehicle Out of Lane
2.5.1	Stopped on Tracks	N/A	Type A	Normal	3.92 m/s^2 (.4 g)	N/A	N/A	N/A	N/A
2.5.2	Start of Approach	NA	Type A	Normal	N/A	N/A	N/A	N/A	N/A
2.6.5	Start of Approach	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	In - Out Left - In
2.6.6	Start of Approach	50 mph	Type A	Normal	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	In - Out Right - In
2.7.1a	Start of Approach	50 mph	Type A	Fault - DSRC	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.7.1b	N/A	50 mph	Type A	Fault - DSRC	N/A	N/A	Dry	0%	N/A
2.7.2	Start of Approach	50 mph	Type A	Fault - RTK Loss	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.7.5	Start of Approach	50 mph	Type A	Fault – Loss of MAP	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A
2.7.6	Start of Approach	50 mph	Type A	Fault – Loss of IEEE 1570	3.92 m/s^2 (.4 g)	2.5 Seconds	Dry	0%	N/A

* **Note**: No tests are planned for Vehicle Type B (Light Truck). Tests for this vehicle type of vehicle were simulated during BT&E.

** **Note**: These deceleration rates were programmed into the braking robot so that the deceleration of the vehicle will be as accurate as possible across tests and test iterations. The deceleration is triggered based on a camera trained to the RCVW DVI for specific alerts, following the perception-reaction time. The professional TRC driver intervened with braking when the robot experienced a malfunction, steering to maintain safety. The test case deceleration rates are based on a reasonable rate (.4 g for light vehicle and .27 g for the heavy truck) as suggested by TRC and greater than the AASHTO 90% rate used in the RCVW warning formula.

*** **Note**: AASHTO Green Book recommends the use of 2.5 seconds perception reaction time. This value reflects observed behavior for the 90th percentile driver

Source: Battelle

Scenario-Based Test Execution and Coordination

RBS integration at the mock railroad crossing along with vehicle configuration took place on October 27, 2020. A series of trial runs were performed this day to: 1) understand vehicle and system performance, 2) driver performance and 3) to practice overall duties for all team members. These trial runs additionally afforded the team the opportunity to calibrate the TRC testing equipment and for the professional driver to understand the different alerts and warnings the system would issue during testing. Scenario-based testing started on October 28, 2020, at 11:00 AM and finalized October 30, 2020, at 4:20 PM.

Table 3 presents a chronologically sequenced characterization summary of the FT&E scenario-based testing activities.

Table 3. Chronological Summary of Test Performed During FT&E

Date	Test Case #	Vehicle Type	Initial Vehicle Speed	Vehicle-Out of Lane	HRI Active Initiation	Pavement Wet/Dry	Grade	RCVW State	# Tests Run	Note
10/28/20	2.2.1 h	Type A	50 mph	N/A	Approach Zone Start	Dry	0%	Normal	30	The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag. Vehicle stopped where we had predicted. Several Faults were raised during testing. See Issuing of System Faults. Results are very consistent.
	2.2.1 e	Type A	35 mph	N/A	Approach Zone Start	Dry	0%	Normal	30	Vehicle stopped where we had predicted. Several Faults were raised during testing. See Issuing of System Faults. Results are very consistent.
	2.2.3	Type C	50 mph	N/A	Approach Zone Start	Dry	0%	Normal	30	The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag. CAN data was being fed to the system to perform calculations. The data was decoded incorrectly by the system and was decided to be disabled, see CAN Communications. The breaking robot was using a deceleration rate slower than desired. See Braking Robot Deceleration Rate. All Heavy Truck runs experience a SPaT Data Not Received error at the exact same location. See DSRC Signal Communications Gap. On run 25, the bounce effect described in Signal Bounce When Vehicle Reaches a Stop is present.
	2.2.5	Type C	35 mph	N/A	Approach Zone Start	Dry	0%	Normal	30	The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag.
	2.2.7	Type A	50 mph	N/A	Approach Zone Start	Wet	0%	Normal	30	Log files show the vehicle was not in lane, see Lane Shift. The Roadside RCVW Plugin needed to be restarted to eliminate processor lags. In this particular test the

Date	Test Case #	Vehicle Type	Initial Vehicle Speed	Vehicle-Out of Lane	HRI Active Initiation	Pavement Wet/Dry	Grade	RCVW State	# Tests Run	Note
										DSRC radio needed a restart as well. See Processor Lag.
	2.2.9	Type A	35 mph	N/A	Approach Zone Start	Wet	0%	Normal	30	There are several runs where the system does not receive any errors. Several Fault Messages were issued during testing. See Issuing of System Faults. On run 6 and 16, the bounce effect described in Signal Bounce When Vehicle Reaches a Stop is present.
	2.5.1	Type A	Stopped in HRI	N/A	With CV in HRI Hazard Zone	-	0%	Normal	30	28 runs presented no errors. Two runs presented a location data frequency too low.
10/29/20	2.1.1	Type A	Vehicle never stops	N/A	Never Active	-	0%	Normal	3	One test case failed due to Camera (Test Equipment) malfunction. A total of three successful test cases were performed. The Roadside RCVW Plugin needed to be restarted to eliminate processor lags. See Processor Lag.
	2.2.8	Type C	50 mph	N/A	Approach Zone Start	Wet	0%	Normal	30	The power connector to the DVI was not properly connected resulting in several aborted tests. TRCs DAQ had issues on runs 26 and 29 resulting in driver activating the brakes. The Roadside RCVW Plugin needed to be restarted to eliminate processor lags. See Processor Lag.
	2.2.10	Type C	35 mph	N/A	Approach Zone Start	Wet	0%	Normal	30	Log files show the vehicle was not in lane in several runs, see Lane Shift. The bounce effect described in Signal Bounce When Vehicle Reaches a Stop is present in several runs. Several Fault Messages were issued during testing. See Issuing of System Faults.

Date	Test Case #	Vehicle Type	Initial Vehicle Speed	Vehicle-Out of Lane	HRI Active Initiation	Pavement Wet/Dry	Grade	RCVW State	# Tests Run	Note
10/30/20	2.6.6	Type A	50 mph	In - Out Right - In	Approach Zone Start	Dry	0%	Normal	3	For safety concerns, the breaking robot was deactivated during the Position Deviation Test Cases. Several Faults were raised during testing. See Issuing of System Faults for more information on this issue. Log files show the vehicle was not in lane, see Lane Shift.
	2.2.1l	Type A	70 mph	N/A	Approach Zone Start	Dry	0%	Normal	3	Several Fault Messages were issued during testing. See Issuing of System Faults.
	2.6.5	Type A	50 mph	In - Out Left - In	Approach Zone Start	Dry	0%	Normal	3	For safety concerns, the breaking robot was deactivated during the Position Deviation Test cases. The vehicle proceeds across the HRI for all the test runs.
	2.4.4	Type A	50 mph	N/A	Approach Zone start, removed at midpoint	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. Several Fault Messages were issued during testing. See Issuing of System Faults.
	2.4.1	Type A	50 mph	N/A	¾ Warning Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. Several Fault Messages were issued during testing. See Issuing of System Faults.
	2.4.2	Type A	50 mph	N/A	Mid-Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. One Test run had to be dropped due to RTK issues. No errors were present in this test.
	2.4.3a	Type A	50 mph	N/A	¼ Warning Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a

Date	Test Case #	Vehicle Type	Initial Vehicle Speed	Vehicle-Out of Lane	HRI Active Initiation	Pavement Wet/Dry	Grade	RCVW State	# Tests Run	Note
										hardware malfunction. Activation was performed manually. Several Fault Messages were issued during testing. See Issuing of System Faults.
	2.4.8	Type A	70 mph	N/A	Mid-Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. Run 3 experienced the issue of an RCVW, cleared and re-issue.
	2.5.2	Type A	Static at different locations	N/A	-	-	0%	Normal	3 runs of 10 minutes	See section System Fault Verification for complete details and results of this test.
10/30/20	2.7.1a	Type A	-	N/A	Approach Zone Start	Dry	0%	Fault	1	Nothing to report
	2.7.1b	Type A	50 mph	N/A	Approach Zone Start	Dry	0%	Fault	1	Nothing to report
	2.7.2	Type A	50 mph	N/A	Approach Zone Start	Dry	0%	Fault	1	Nothing to report
	2.7.5	Type A	50 mph	N/A	Approach Zone Start	Dry	0%	Fault	1	The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag.
	2.7.6	Type A	50 mph	N/A	Approach Zone Start	Dry	0%	Fault	1	Nothing to report
	2.3.1	Type A	35 mph	N/A	Approach Zone Start	Dry	-10%	Normal	7	Several Fault Messages were issued during testing. See Issuing of System Faults. RTK Fix was achieved during all runs.

Date	Test Case #	Vehicle Type	Initial Vehicle Speed	Vehicle-Out of Lane	HRI Active Initiation	Pavement Wet/Dry	Grade	RCVW State	# Tests Run	Note
	2.4.9	Type C	50 mph	N/A	¾ Warning Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. In this test the Heavy Truck did not experience any SPaT errors.
	2.4.3b	Type C	50 mph	N/A	¼ Warning Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. In this test the Heavy Truck did not experience any SPaT errors.
	2.2.6	Type C	60 mph	N/A	Approach Zone Start	Dry	0%	Normal	3	The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag.
	2.4.7	Type C	50 mph	N/A	Mid-Point	Dry	0%	Normal	3	The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. Several Fault Messages were issued during testing. See Issuing of System Faults.

Table 4 provides a summary list of the RCVW FT&E test cases. The table distinguishes test cases that are scenario-based versus those that are not, and specifies how the tested requirements are verified (I = inspect, T = test, D = demonstrate, and A = analyze) in each test case. Within the test cases, two vehicle types are referenced and are defined as follows:

- Type A = Passenger Car
- Type C = Heavy Truck

Note: Type B (Light Truck) vehicles were simulated in BT&E.

Table 4. Summary of FT&E Test Cases

Test Case No.	Test Case Title	Phase II Discrete FT&E Verification	Phase II Scenario-Based FT&E Verification
2.1.1	Type A CV Approaches and Travels through HRI with no Train Approaching, 50 mph – No HRI Active Signal		D, A
2.2.1e	Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions		D, A
2.2.1h	Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions		D, A
2.2.1l	Type A CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions		D, A
2.2.3	Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions		D, A
2.2.5	Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions		D, A
2.2.6	Type C CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions		D, A
2.2.7	Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions		D, A
2.2.8	Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions		D, A
2.2.9	Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions		D, A
2.2.10	Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions		D, A
2.3.1	Type A CV Approaches with Preemption Signal Detected at Approach Entry, Road Grade -10%, 35 mph		D, A
2.4.1	Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions		D, A
2.4.2	Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions		D, A
2.4.3a	Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions		D, A

Test Case No.	Test Case Title	Phase II Discrete FT&E Verification	Phase II Scenario-Based FT&E Verification
2.4.3b	Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions		D, A
2.4.4	Type A CV Approaches with Preemption Signal Detected at Approach Entry, Preemption signal is removed at Midpoint, 50 mph, Dry Conditions		D, A
2.4.7	Type C CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions		D, A
2.4.8	Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 70 mph, Dry Conditions		D, A
2.4.9	Type C CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions		D, A
2.5.1	CV Stopped in HRI Hazard Zone		D, A
2.5.2	CV Stopped, Enter/Exit the HRI with Preemption Active		D, A
2.6.5	Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Left of the Approach Zone, CV Position Re-enters Approach Zone, 50 mph, Dry Conditions		D, A
2.6.6	Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Right of the Approach zone, CV Position Enters Approach Zone, 50 mph, Dry Conditions		D, A
2.7.1a	Loss of DSRC after CV has received an RCVW		D, A
2.7.1b	Loss of DSRC Prior to entering the MAP		D, A
2.7.2	Loss of RTK Fix (GPS)		D, A
2.7.5	Loss of MAP		D, A
2.7.6	Loss of IEEE 1570 Heartbeat		D, A

During testing, datasheets were used to manually record the following observed details for post-testing reconciliation and analysis with log files. The Battelle team was able to remotely connect to both RCVW VBS units (truck and light vehicle) and continually monitor the system performance. For each test iteration, times were recorded in HH:MM:SS as taken from RCVW application internal clock. Information recorded included:

- Test start
- Test ending
- Any fault being issued during the test run
- Deceleration rates as reported by the CV driver
- RTK status

- General test observations

Table 5 summarizes test team personnel location and responsibilities, including data collection details. The control station was located near the roadside controller cabinet in which the RCVW RBS was integrated.

Table 5. Test Team Locations and Responsibilities for Scenario-Based FT&E Test Cases

Location	Responsibility	Action	Collection
CV	Driver	• Accelerate CV to specified initial approach speed • Perform any swerving maneuvers (as needed) • Monitor in vehicle test equipment	• Deceleration rates which were provided via radio to Test Director • Input test number and test iteration on TRC equipment
Control Station	Test Director	• Coordinate test sequence • Maintain radio communication between tests to relay/receive observation data and to coordinate and prepare for the next test • Collect data specified	• Record test start and end time • Record any oddities or situations for future resolution • Record time of preemption switch ON/OFF (where applicable)
Control Station	Algorithm Observers	• Control preemption signal activation/de-activation (where applicable) • Monitor algorithm performance for errors and communicate any anomalies	• Collect log files

FT&E Results Reconciliation Approach and Results Summary

RCVW data from two sources was used in the reconciliation of the FT&E results: 1) Transportation Message Exchange (TMX) core plugin logs from the VBS and 2) PCAP (or packet capture) files of DSRC communication details from the RBS and VBS DSRC radios.

VBS TMX Core Log Based Analysis

VBS TMX core log files contain records of all state changes sent to the DVI from the RCVW plugin, including:

- Application Active / Inactive states – indicating that preemption is on or off when a CV is within the MAP area ingress lane (or Approach Zone)
- Rail Crossing Violation Warning issuance and clearance states – indicating when an RCVW warning is issued and cleared
- Vehicle Stopped at HRI Warning – issuance and clearance states - indicating when a ‘Clear HRI’ Warning is issued and cleared)
- Error activation and clearance messages (when an expected message is not received by the VBS from the RBS RSU, such as MAP or SPaT data, or when GPS communications are degraded

TMX core log files additionally contain periodically recorded details from its input sources including location information from GNSS and J2735 messages from DSRC. Other calculated values used as position-based determinants in the warning/alerting state changes described above. Some key recorded log details include:

- Latitude (GNSS)
- Longitude (GNSS)
- Heading (GNSS)
- In-Lane Status (True/False)
- Horizontal Dilution of Precision (HDOP) GPS horizontal precision quality marker
- Speed (GPS and CAN)
- Preemption Status (HRI active signal, from J2735 SPaT message)
- Distance to the railroad crossing (calculated value by the RCVW application)
- Safety Stop Distance (calculated value by the RCVW application – distance determined to be needed given the current instantaneous conditions)

All TMX core log records are time stamped, with time expressed in Universal Time Code (UTC).

The following series of three TMX core log file excerpts are from FT&E, as noted.

Example 1 (Test 2.2.1e Iteration #24): Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions. The log files show the system issuing an “Application Available” message on the DVI, followed by an Approach Inform Alert

```
tmxcore[1954]: [2020-10-28 16:26:03.026] WPlugin/src/RCVWPlugin.cpp (945) - DEBUG  : IsInLane: true, IsNearLane: false, LaneNumber: 21, LaneSegment: 9, Grade: 0
tmxcore[1954]: [2020-10-28 16:26:03.028] Plugin/src/RCVWPlugin.cpp (1200) - DEBUG  : Latitude: 40.3122393, Longitude: -83.554041, Speed: 16.075, PrevSpeed: 16.075, HDOP: 0.72, Preemption: true
tmxcore[1954]: [2020-10-28 16:26:03.029] Plugin/src/RCVWPlugin.cpp (1262) - DEBUG  : VBM Acceleration: -16.7002, expectedStopDistance: 7.736602705
tmxcore[1954]: [2020-10-28 16:26:03.029] Plugin/src/RCVWPlugin.cpp (1268) - DEBUG  : CrossingDistance: 457.9397031, SafetyStopDistanceV1: 48.83242586, SafetyStopDistance: 90.81397586, ExpectedStopDistance: 7.736602705
tmxcore[1954]: [2020-10-28 16:26:03.046] Plugin/src/RCVWPlugin.cpp (1090) - DEBUG  : Sending Application Message: Available
tmxcore[1954]: [2020-10-28 16:26:03.048] Plugin/src/RCVWPlugin.cpp (1102) - DEBUG  : Sending Application Message: ApproachInform
tmxcore[1954]: [2020-10-28 16:26:03.092] WPlugin/src/RCVWPlugin.cpp (722) - DEBUG  : LOC TIME, LOC SPEED, LOC HEADING, SPEED, HEADING, RTK, FREQUENCY: 1603916763000, 15.749, 327.434, 16.075, 327.434, fixed, 10
tmxcore[1954]: [2020-10-28 16:26:03.105] mxUtils/src/MapSupport.cpp (371) - DEBUG  : inLaneDistance, stopBarDistance, segmentLength: 29.3209, 427.032, 31.6368
tmxcore[1954]: [2020-10-28 16:26:03.105] mxUtils/src/MapSupport.cpp (372) - DEBUG  : p2.Elevation, pointElevation, res.Grade: 0, 0, 0
tmxcore[1954]: [2020-10-28 16:26:03.105] WPlugin/src/RCVWPlugin.cpp (913) - DEBUG  : Lane, SignalGroup = 21, 2
```

The vehicle continues its approach at 35 mph and receives an Application Error message as a result of the loss of SPaT

```
tmxcore[1954]: [2020-10-28 16:26:16.378] WPlugin/src/RCVWPlugin.cpp (945) - DEBUG  : IsInLane: true, IsNearLane: false, LaneNumber: 21, LaneSegment: 5, Grade: 0
tmxcore[1954]: [2020-10-28 16:26:16.379] Plugin/src/RCVWPlugin.cpp (1200) - DEBUG  : Latitude: 40.3138366, Longitude: -83.5553814, Speed: 15.35555556, PrevSpeed: 15.35555556, HDOP: 0.72, Preemption: true
tmxcore[1954]: [2020-10-28 16:26:16.379] Plugin/src/RCVWPlugin.cpp (1262) - DEBUG  : VBM Acceleration: -19.7627, expectedStopDistance: 5.965609113
tmxcore[1954]: [2020-10-28 16:26:16.379] Plugin/src/RCVWPlugin.cpp (1268) - DEBUG  : CrossingDistance: 247.0772528, SafetyStopDistanceV1: 45.59006992, SafetyStopDistance: 85.40774191, ExpectedStopDistance: 5.965609113
tmxcore[1954]: [2020-10-28 16:26:16.424] Plugin/src/RCVWPlugin.cpp (1138) - DEBUG  : Sending Application Message: Error: SPAT Data Not Received
tmxcore[1954]: [2020-10-28 16:26:16.427] Plugin/src/RCVWPlugin.cpp (1096) - DEBUG  : Sending Application Message: Clear Available
tmxcore[1954]: [2020-10-28 16:26:16.429] Plugin/src/RCVWPlugin.cpp (1108) - DEBUG  : Sending Application Message: Clear ApproachInform
tmxcore[1954]: [2020-10-28 16:26:16.474] WPlugin/src/RCVWPlugin.cpp (722) - DEBUG  : LOC TIME, LOC SPEED, LOC HEADING, SPEED, HEADING, RTK, FREQUENCY: 1603916776400, 15.705, 327.177, 15.3556, 327.177, fixed, 10
tmxcore[1954]: [2020-10-28 16:26:16.531] WPlugin/src/RCVWPlugin.cpp (750) - DEBUG  : VBM SPEED, VBM ACCELERATION: 15.35555556, -19.7627
```

Example 2 (Test 2.2.7 Iteration #27): Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions. The log files show the system issuing an “ApproachWarning” message on the DVI

```
tmxcore[1958]: [2020-10-29 11:56:35.279] WPlugin/src/RCVWPlugin.cpp (945) - DEBUG  : IsInLane: true, IsNearLane: false, LaneNumber: 21, LaneSegment: 4, Grade: 0
tmxcore[1958]: [2020-10-29 11:56:35.280] Plugin/src/RCVWPlugin.cpp (1200) - DEBUG  : Latitude: 40.3146157, Longitude: -83.5560326, Speed: 22.55833333, PrevSpeed: 22.55833333, HDOP: 0.78, Preemption: true
tmxcore[1958]: [2020-10-29 11:56:35.280] Plugin/src/RCVWPlugin.cpp (1262) - DEBUG  : VBM Acceleration: -19.8105, expectedStopDistance: 12.84365369
tmxcore[1958]: [2020-10-29 11:56:35.280] Plugin/src/RCVWPlugin.cpp (1268) - DEBUG  : CrossingDistance: 144.3456227, SafetyStopDistanceV1: 82.51846965, SafetyStopDistance: 146.4074967, ExpectedStopDistance: 12.84365369
tmxcore[1958]: [2020-10-29 11:56:35.285] Plugin/src/RCVWPlugin.cpp (1114) - DEBUG  : Sending Application Message: ApproachWarning
tmxcore[1958]: [2020-10-29 11:56:35.350] WPlugin/src/RCVWPlugin.cpp (750) - DEBUG  : VBM SPEED, VBM ACCELERATION: 22.55555556, -19.8105
tmxcore[1958]: [2020-10-29 11:56:35.357] WPlugin/src/RCVWPlugin.cpp (750) - DEBUG  : VBM SPEED, VBM ACCELERATION: 22.55555556, -19.8105
tmxcore[1958]: [2020-10-29 11:56:35.392] WPlugin/src/RCVWPlugin.cpp (722) - DEBUG  : LOC TIME, LOC SPEED, LOC HEADING, SPEED, HEADING, RTK, FREQUENCY: 1603986995300, 22.377, 327.011, 22.5556, 327.011, fixed, 10
tmxcore[1958]: [2020-10-29 11:56:35.405] mxUtils/src/MapSupport.cpp (371) - DEBUG  : inLaneDistance, stopBarDistance, segmentLength: 50.8884, 91.2206, 91.5966
tmxcore[1958]: [2020-10-29 11:56:35.405] mxUtils/src/MapSupport.cpp (372) - DEBUG  : p2.Elevation, pointElevation, res.Grade: 0, 0, 0
tmxcore[1958]: [2020-10-29 11:56:35.405] WPlugin/src/RCVWPlugin.cpp (913) - DEBUG  : Lane, SignalGroup = 21, 2
```

Example 3 (Test 2.5.1, iteration #2): CV Stopped in HRI Hazard Zone. The log file shows the system issuing an “HRI Warning” Message on the DVI

```
tmxcore[1951]: [2020-10-29 15:37:55.789] Plugin/src/RCVWPlugin.cpp (1200) - DEBUG  : Latitude: 40.3157284, Longitude: -83.5569643, Speed: 0.1444444444, PrevSpeed: 0.1444444444, HDOP: 0.57, Preemption: false
tmxcore[1951]: [2020-10-29 15:37:55.789] Plugin/src/RCVWPlugin.cpp (1262) - DEBUG  : VBM Acceleration: -19.7148, expectedStopDistance: 0.0005291506262
tmxcore[1951]: [2020-10-29 15:37:55.789] Plugin/src/RCVWPlugin.cpp (1268) - DEBUG  : CrossingDistance: -1, SafetyStopDistanceV1: 0.2186626039, SafetyStopDistance: 6.778627189, ExpectedStopDistance: 0.0005291506262
tmxcore[1951]: [2020-10-29 15:37:55.795] Plugin/src/RCVWPlugin.cpp (1126) - DEBUG  : Sending Application Message: HRIWarning
tmxcore[1951]: [2020-10-29 15:37:55.882] WPlugin/src/RCVWPlugin.cpp (722) - DEBUG  : LOC TIME, LOC SPEED, LOC HEADING, SPEED, HEADING, RTK, FREQUENCY: 1604000275800, 0.208, 329.235, 0.144444, 329.235, fixed, 10
tmxcore[1951]: [2020-10-29 15:37:55.891] WPlugin/src/RCVWPlugin.cpp (913) - DEBUG  : Lane, SignalGroup = 0, -1
```

Reconciling the VBS TMX core log files included the following observations:

- All expected state changes are log,ged and no unexpected state changes were seen, based on the test case scenario executed
- State changes logged are appropriate relative to calculated or reported TMX core log values (e.g., “HRI Warning” is issued when vehicle speed is zero and vehicle is within the HRI, and “ApproachWarning” is issued when calculated safety stop distance exceeds calculated crossing distance and clears when crossing distance exceeds safety stop distance or when vehicle crosses into the HRI or when preemption state is false, etc.

A more detailed analysis is performed when reconciling the VBS TMX core log file data to the data from the ground truth system. A comparison of the position data from the VBS TMX core log file to the data from the ground truth high precision GNSS/INS was done to obtain an overall accuracy. This process consisted of several steps to align the data and extract maximum useful information. First, the data was aligned to the nearest logged time stamp. In this case the ground truth data was sampled at ten times the rate of the TMX VBS, which allowed for a time accuracy within ±5 ms. Because both time sources were GNSS-based this should result in a highly reliable and consistent synchronization (<100 ns). The ground truth data was down sampled to select only the data that was closest to the time stamp of each Latitude/Longitude data point form the TMX VBS core log file. Next both sets of points were converted to planar coordinates in meters with the center of the stop bar as the origin. Finally, the points were rotated along the heading of the lane so that longitudinal and lateral position offsets, that is error, could be determined between the two systems. The magnitude of the total error was taken, as well as the individual components.

A comparison velocity data from both the GNSS (both vehicle types) and CAN (Vehicle type A only) VBS TMX core log file to the ground truth system was performed. The time was synchronized similar to the positioning accuracy analysis, relying on the time stamp of each system’s data. In this case, the data was synchronized independently between the GNSS-based and the CAN-based velocity. The magnitude of the error was logged.

Alert generation was compared using data from the application log in the VBS TMX core log file and a DVI camera-based detection system. The DVI camera-based detection system looked at the Red Green Blue (RGB) value of a small section of the DVI, as shown in Figure 13. The system looked for when the RGB value changed to the calibrated level of the warning screen. This was time stamped logged in the system and triggered braking of the vehicle at the defined deceleration after the average human reaction time of 2.5 s. The alert generation was compared in several ways. First, the distance the alert was supposed to be generated was calculated based on the equation in the RCVW system using the course and ground-truth vehicle velocity. The equation included multiple error-compensating factors (both distance and time-based) making this the best-case scenario for when the alert should be generated. Second, the distance from the stop bar was calculated based on the VBS TMX log (not DVI) time and position. Third, the distance from the stop bar was calculated based on the VBS TMX log time (not DVI) using the ground time position. Finally, the distance from the stop bar was calculated based on the DVI display using the ground truth time and position shown in Figure 15.

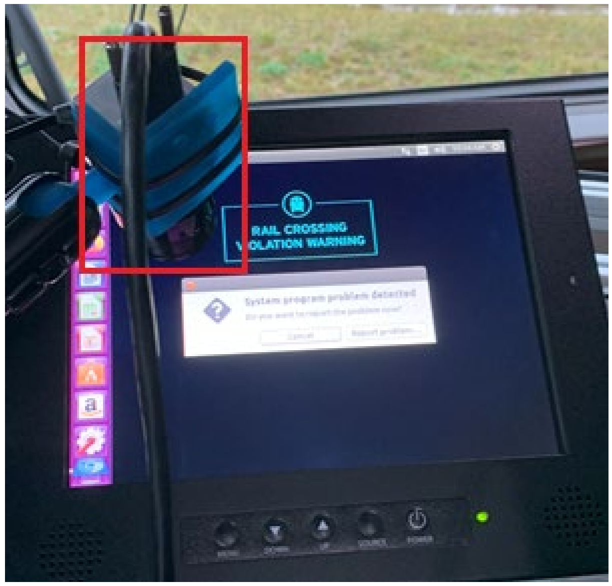


Figure 15. DVI and Camera-Based Detection (red box) in the Heavy Truck

Paquet Capture Log Files Based Analysis

Paquet Capture (PCAP) files contain the J2735 SPaT and MAP messages being sent and received from both the roadside and vehicle based the DSRC radios are used to analyze the latency requirements of the system. All PCAP messages logged provide the following

- A time stamp (sent and received depending on the source)
- A message length
- A message frame which includes message id, intersection geometry (for the MAP) and intersection state (for the SPaT) which includes preemption information.

The following (see Figure 16) is an example of the PCAP file from the Roadside Radio (transmitting) for the last day of testing.

```
108 2020-10-30 14:00:29.815838 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    140 signalPhaseAndTimingMessage
109 2020-10-30 14:00:29.834504 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    347 mapData
110 2020-10-30 14:00:29.874666 CohdaWir_10:12:36    Broadcast    WSA                 191 IEEE 1609.3-2016 WSA
111 2020-10-30 14:00:29.918196 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    140 signalPhaseAndTimingMessage
112 2020-10-30 14:00:29.964984 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    189 rtcmCorrections
113 2020-10-30 14:00:29.965493 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    108 rtcmCorrections
114 2020-10-30 14:00:29.974541 CohdaWir_10:12:36    Broadcast    WSA                 191 IEEE 1609.3-2016 WSA
115 2020-10-30 14:00:29.999463 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    119 rtcmCorrections
116 2020-10-30 14:00:30.008825 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    240 rtcmCorrections
117 2020-10-30 14:00:30.062805 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    225 rtcmCorrections
118 2020-10-30 14:00:30.063244 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    140 signalPhaseAndTimingMessage
119 2020-10-30 14:00:30.063657 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    119 rtcmCorrections
120 2020-10-30 14:00:30.063998 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    254 rtcmCorrections
121 2020-10-30 14:00:30.064443 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    240 rtcmCorrections
122 2020-10-30 14:00:30.074752 CohdaWir_10:12:36    Broadcast    WSA                 191 IEEE 1609.3-2016 WSA
123 2020-10-30 14:00:30.161716 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    119 rtcmCorrections
124 2020-10-30 14:00:30.162414 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    254 rtcmCorrections
125 2020-10-30 14:00:30.162621 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    140 signalPhaseAndTimingMessage
126 2020-10-30 14:00:30.162845 CohdaWir_10:12:36    Broadcast    SAE J2735 (2016)    119 rtcmCorrections

    name: TRC Smart Center Railway
  > id
    revision: 1
    status: 0000 [bit length 16, 0000 0000  0000 0000 decimal value 0]
    moy: 437400
    timeStamp: 29809 (29.809 sec)
  v states: 2 items
    v Item 0
      v MovementState
          signalGroup: 1
        v state-time-speed: 1 item
          v Item 0
            v MovementEvent
                eventState: stop-And-Remain (3)
              > timing
```

Figure 16. PCAP File Example

The protocol analysis tool called Wireshark was used to export the necessary data from the PCAP files into an excel spreadsheet format. The data was then filtered to extract only the MAP and SPAT data that was sent by the roadside unit and received by the vehicle-based radio for each of the test run iterations. The sent messages were then correlated to the received messages. The timestamp was then used to calculate the latency of the broadcasted message.

Figure 17 is an example of the analyzed MAP latency data. The detailed results of the analysis can be found in DSRC Messaging and Data Processing Latency Requirement Verification.

RBS MAP SENT	VBS MAP RECEIVE	MAP LATENCY	Data for Graphs	MAP ENTRIES FOR CALCULATIONS		
10:21:06.165	10:21:06.167	0:00:00.002	0.002314482	0.002314482		
10:21:07.173	10:21:07.175	0:00:00.002	0.00231521	0.00231521	Start Time	10:21:06.165
10:21:08.177	10:21:08.178	0:00:00.001	0.001157605	0.001157605	End time	10:21:45.215
10:21:09.175	10:21:09.176	0:00:00.001	0.001157605	0.001157605	Run Time	0:00:39.050
10:21:10.168	10:21:10.170	0:00:00.002	0.00231521	0.00231521	MAP MESSAGES	41
10:21:11.173	10:21:11.174	0:00:00.001	0.001156877	0.001156877		
10:21:12.176	10:21:12.177	0:00:00.001	0.001156877	0.001156877	Average MAP per secon	1.04993598
10:21:13.177	10:21:13.179	0:00:00.002	0.002314482	0.002314482		
10:21:14.183	10:21:14.184	0:00:00.001	0.001157605	0.001157605	Average MAP latency	0.00240163
10:21:15.177	10:21:15.179	0:00:00.002	0.00231521	0.00231521		
10:21:16.184	10:21:16.186	0:00:00.002	0.002314482	0.002314482		
10:21:17.179	10:21:17.181	0:00:00.002	0.002314482	0.002314482		
10:21:18.180	10:21:18.182	0:00:00.002	0.00231521	0.00231521		
10:21:19.179	10:21:19.180	0:00:00.001	0.001157605	0.001157605		
10:21:20.182	10:21:20.185	0:00:00.003	0.003472087	0.003472087		
10:21:21.206	10:21:21.208	0:00:00.002	0.00231521	0.00231521		
10:21:22.181	10:21:22.183	0:00:00.002	0.002314482	0.002314482		
10:21:23.184	10:21:23.186	0:00:00.002	0.00231521	0.00231521		
10:21:24.218	10:21:24.221	0:00:00.003	0.003472087	0.003472087		
10:21:25.187	10:21:25.188	0:00:00.001	0.001156877	0.001156877		
10:21:26.192	10:21:26.194	0:00:00.002	0.002314482	0.002314482		
10:21:27.198	10:21:27.203	0:00:00.005	0.005787297	0.005787297		
10:21:28.192	10:21:28.194	0:00:00.002	0.00231521	0.00231521		
10:21:29.200	10:21:29.206	0:00:00.006	0.006944174	0.006944174		
10:21:30.197	10:21:30.199	0:00:00.002	0.00231521	0.00231521		
10:21:31.205	10:21:31.209	0:00:00.004	0.004629692	0.004629692		
10:21:32.198	10:21:32.199	0:00:00.001	0.001157605	0.001157605		
10:21:33.202	10:21:33.205	0:00:00.003	0.003472087	0.003472087		
10:21:34.200	10:21:34.205	0:00:00.005	0.005787297	0.005787297		
10:21:35.204	10:21:35.205	0:00:00.001	0.001157605	0.001157605		
10:21:36.202	10:21:36.205	0:00:00.003	0.003472087	0.003472087		
10:21:37.205	10:21:37.206	0:00:00.001	0.001157605	0.001157605		
10:21:38.243	10:21:38.245	0:00:00.002	0.002314482	0.002314482		
10:21:39.208	10:21:39.209	0:00:00.001	0.001157605	0.001157605		
10:21:40.208	10:21:40.210	0:00:00.002	0.00231521	0.00231521		
10:21:41.209	10:21:41.211	0:00:00.002	0.002314482	0.002314482		
10:21:42.211	10:21:42.212	0:00:00.001	0.001157605	0.001157605		
10:21:43.209	10:21:43.211	0:00:00.002	0.00231521	0.00231521		
10:21:44.212	10:21:44.214	0:00:00.002	0.002314482	0.002314482		
10:21:45.215	10:21:45.216	0:00:00.001	0.001156877	0.001156877		

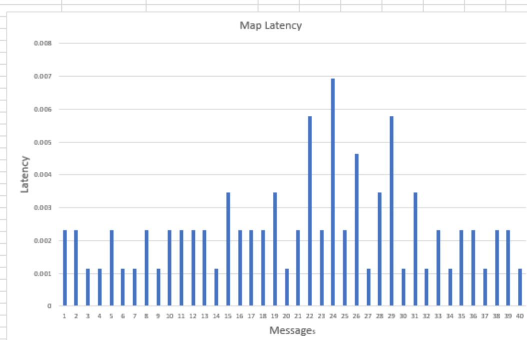
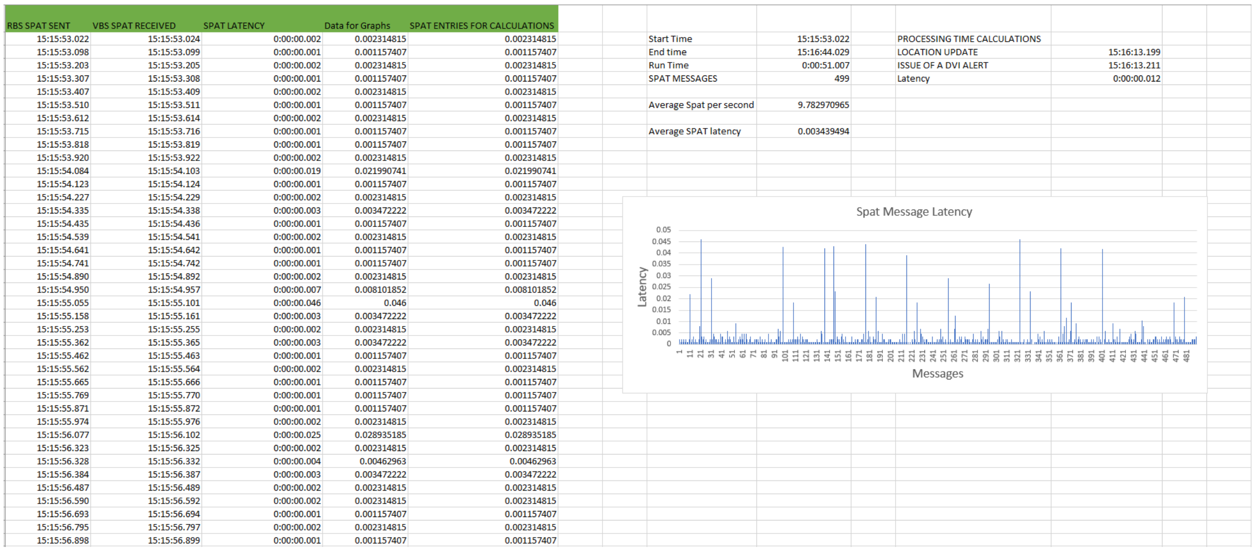


Figure 17. MAP Message Latency Analysis

A similar analysis was performed for SPaT message latency (see Figure 18). The detailed results of the analysis can be found in DSRC Messaging and Data Processing Latency Requirement Verification.



RBS SPAT SENT	VBS SPAT RECEIVED	SPAT LATENCY	Data for Graphs	SPAT ENTRIES FOR CALCULATIONS
15:15:53.022	15:15:53.024	0:00:00.002	0.002314815	0.002314815
15:15:53.098	15:15:53.099	0:00:00.001	0.001157407	0.001157407
15:15:53.203	15:15:53.205	0:00:00.002	0.002314815	0.002314815
15:15:53.307	15:15:53.308	0:00:00.001	0.001157407	0.001157407
15:15:53.407	15:15:53.409	0:00:00.002	0.002314815	0.002314815
15:15:53.510	15:15:53.511	0:00:00.001	0.001157407	0.001157407
15:15:53.612	15:15:53.614	0:00:00.002	0.002314815	0.002314815
15:15:53.715	15:15:53.716	0:00:00.001	0.001157407	0.001157407
15:15:53.818	15:15:53.819	0:00:00.001	0.001157407	0.001157407
15:15:53.920	15:15:53.922	0:00:00.002	0.002314815	0.002314815
15:15:54.084	15:15:54.103	0:00:00.019	0.021990741	0.021990741
15:15:54.123	15:15:54.124	0:00:00.001	0.001157407	0.001157407
15:15:54.227	15:15:54.229	0:00:00.002	0.002314815	0.002314815
15:15:54.335	15:15:54.338	0:00:00.003	0.003472222	0.003472222
15:15:54.435	15:15:54.436	0:00:00.001	0.001157407	0.001157407
15:15:54.539	15:15:54.541	0:00:00.002	0.002314815	0.002314815
15:15:54.641	15:15:54.642	0:00:00.001	0.001157407	0.001157407
15:15:54.741	15:15:54.742	0:00:00.001	0.001157407	0.001157407
15:15:54.890	15:15:54.892	0:00:00.002	0.002314815	0.002314815
15:15:54.950	15:15:54.957	0:00:00.007	0.008101852	0.008101852
15:15:55.055	15:15:55.101	0:00:00.046	0.046	0.046
15:15:55.158	15:15:55.161	0:00:00.003	0.003472222	0.003472222
15:15:55.253	15:15:55.255	0:00:00.002	0.002314815	0.002314815
15:15:55.362	15:15:55.365	0:00:00.003	0.003472222	0.003472222
15:15:55.462	15:15:55.463	0:00:00.001	0.001157407	0.001157407
15:15:55.562	15:15:55.564	0:00:00.002	0.002314815	0.002314815
15:15:55.665	15:15:55.666	0:00:00.001	0.001157407	0.001157407
15:15:55.769	15:15:55.770	0:00:00.001	0.001157407	0.001157407
15:15:55.871	15:15:55.872	0:00:00.001	0.001157407	0.001157407
15:15:55.974	15:15:55.976	0:00:00.002	0.002314815	0.002314815
15:15:56.077	15:15:56.102	0:00:00.025	0.028935185	0.028935185
15:15:56.323	15:15:56.325	0:00:00.002	0.002314815	0.002314815
15:15:56.328	15:15:56.332	0:00:00.004	0.00462963	0.00462963
15:15:56.384	15:15:56.387	0:00:00.003	0.003472222	0.003472222
15:15:56.487	15:15:56.489	0:00:00.002	0.002314815	0.002314815
15:15:56.590	15:15:56.592	0:00:00.002	0.002314815	0.002314815
15:15:56.693	15:15:56.694	0:00:00.001	0.001157407	0.001157407
15:15:56.795	15:15:56.797	0:00:00.002	0.002314815	0.002314815
15:15:56.898	15:15:56.899	0:00:00.001	0.001157407	0.001157407

Start Time	15:15:53.022	PROCESSING TIME CALCULATIONS	
End time	15:16:44.029	LOCATION UPDATE	15:16:13.199
Run Time	0:00:51.007	ISSUE OF A DVI ALERT	15:16:13.211
SPAT MESSAGES	499	Latency	0:00:00.012
Average Spat per second	9.782970965		
Average SPAT latency	0.003439494		

Figure 18. SPaT Message Latency Analysis

Summary of RCVW Performance

A detailed account of all FT&E test results can be found in the next chapter, and a summary of performance by requirement can be found in Appendix. In summary all requirements were confirmed to have been met with one exception: 1) requirement RBS-4 was not confirmed (see DSRC Messaging and Data Processing Latency Requirement Verification).

Across the scenarios focused on assessing violation detections with the CV on approach (i.e., Test Cases 2.1.X – 2.6.X) the RCVW system was found to always warn the driver when the vehicle was approaching the active crossing at a speed calculated to be too fast for the stopping distance (using the calculations and parameters described above). Following the actions of the programmed breaking robot, the vehicle was able to safely decelerate and stop both vehicle types before reaching the crossing—except in some cases when the deceleration rate of the breaking robot was not correct (see Braking Robot Deceleration Rate) and when the train preemption was delivered late (see Dilemma Zone).

Positional Accuracy

The accuracy of the positional subsystem varied based on the vehicle and velocity. The accuracy can be broken into two different categories, processing-latency based error and positional based error. Processing-latency based error is a result of the movement of the vehicle over the duration of time it takes to receive the measured position from the GNSS receiver and can be identified by a proportional error based on the velocity of the vehicle (including the heading of the vehicle). The positional error is a result of the GNSS Module inherent accuracy when compared to a ground truth system (RT3003 High Accuracy Multi-Axis GNSS aided Inertial Navigation System used for comparison). This error value is constant across speeds. The total positional error, consisting of both the processing latency based and positional-based component is divided in this section with respect to longitudinal and lateral errors to help understand potential causation.

GNSS Module Comparative Analysis

Prior to field testing, a position solution comparative analysis was performed. One of the goals of this analysis was to compare the accuracy of the selected RCVW RTK enhanced GNSS module (before connecting to the RCVW system) to a high performance, professional grade RTK device (to be considered the "truth" system). The selected GNSS module was connected directly to a laptop and the location information was gathered using the vendor specific software application called Ublox Ucenter. This configuration allowed a specific measurement and recording of the accuracy of the GNSS module. This analysis was performed on both a flat course and the graded course. The truth unit and the GNSS module received RTCM corrections from two separate base stations in the flat course due to network limitations. The high performance RTK device received RTCM corrections via a nearby local networked RTK base station while the selected GNSS module received its corrections from a remote virtual reference station. In the case of the graded course, both devices connected to the remote virtual reference station.

The analysis showed a stable error measurement of 1.01 m at 35 mph at the flat course and 0.25 m at the graded course. These data show that the RCVW RTK device did not achieve the level of accuracy advertised by the manufacturer (1 cm 50% Circular Error Probable [CEP]) and performed better in the more challenging environment presented at the graded course (reduced satellite line of sight due to tree foliage). It is likely the difference in accuracy between the two test tracks is due to the use of different base reference stations. This observation is what led us to integrate the RTK base station with the RBS, allowing all the systems within range of the RBS to receive RTCM corrections from the same source, resulting in a higher level of accuracy near the HRI. Since the use of the same reference station by both systems was demonstrated in the comparative analysis to result in an accuracy much closer to the manufacturers specifications, it was decided to omit the measurement of the static positional error for the field test results.

Field Test Positional Accuracy Analysis

The analysis from the field test data presents the positioning error of the system as a whole (GNSS RTK module plus system latencies). Test data show that various latencies resulting from the RCVW system processing the GPS data cause a linear increase in longitudinal error as vehicle speed increases. Both the roadside and vehicle-based subsystems decode and encode GPS data produced by the GNSS module to be sent and received over the DSRC radio. This process increases latencies and has an effect on the positional accuracy.

Table 6 and Table 7 show data collected during the field test and evaluation period. The data show the average longitudinal error for vehicle Type A and Type C at various speeds. This error has a direct impact on warning generation as the vehicle travels toward the HRI. The data suggests that a large component of the longitudinal error is processing-latency based since the research team are expecting better than 1.01 m

GNSS accuracy due to implementation of an RTK base station at the RBS (see GNSS Module Comparative Analysis). The data show a difference in longitudinal error between Type A and Type C vehicles of approximately 3 meters. The error is not of a high concern as long as it is in the longitudinal axis because the equation for the stop bar allows for the 3.12 m GPS error entered in the configurable parameter. However, given the submeter advertised accuracy of the RTK unit, the vehicle type C seems to indicate there are other factors affecting the accuracy. One possibility could be the large overhang from the dump truck bed causing degraded performance and possibly causing the error to be consistently in the same direction. The tables also show the lateral error ranged from 0.02 to 0.64 m for the Type A vehicle and 0.62 to 0.84 m for the Type C vehicle. The velocity error given here shows that this error is generally small compared with speed. and could only contribute a small amount of error to the RCVW distance calculation.

Table 6. Vehicle Type A Accuracy Performance

	Average Error (m)						Velocity Error (m/s)	
Target Speed (mph)	All Data	Before RCVW Warning	After RCVW Warning 30 mph< Speed < 45 mph	After RCVW Warning Speed < 30 mph	Longitudinal	Lateral	GPS Based	Vehicle Based
35 (Flat Course)	1.21	1.30	1.20	0.51	-1.19	0.04	0.35	0.31
50 (Flat Course)	1.57	1.81	1.36	0.61	-1.41	-0.15	0.35	0.26
70 (Flat Course)	2.07	2.69	1.45	0.46	-2.05	0.02	0.44	0.29
35 (Graded Course)	1.30	1.38			-0.84	0.64	0.39	0.31

Table 7. Vehicle Type C Accuracy Performance

	Average Error (m)						Velocity Error (m/s)
Target Speed (mph)	All Data	Before RCVW Warning	After RCVW Warning 30 mph< Speed < 45 mph	After RCVW Warning Speed < 30 mph	Longitudinal	Lateral	GPS Based
35 (Flat Course	4.13	4.28	4.15	3.41	-3.93	0.84	0.11
50 (Flat Course)	4.54	4.87	4.40	3.55	-4.41	0.62	0.17
60 (Flat Course)	4.46	5.02	4.21	3.37	-4.33	0.63	0.19

Alert Performance

Alert generation performance is summarized in Table 8. The table breaks out three different performance metrics based on the RCVW equation and the velocity from the ground truth system. The Alert Equation vs DVI distance column in the table, shows the ground truth distance in meters between the RCVW system equation to when the alert displayed on the DVI. The Alert Equation vs System Generation column shows the ground truth distance between the equation and when the alert was generated internally. And finally, the Alert Equation vs Ground Truth column shows the ground truth distance between the RCVW equation and the GPS location that generated the Warning.

Table 9 shows the error allowed at different speeds in the RCVW equation. When comparing the "Total Distance" column on Table 9 to the "Alert Equation vs DVI" column on Table 8, it can be seen that the time based error (communication and processing latency) and GPS error of the system is within the error allowed by the distance equation. Is worth noticing that the 0.3 seconds shown for communication latency is the value entered in the configurable parameter and represents a maximum threshold used in the warning distance calculation. This value was used across all tests. A processing latency is included in the equation which shows the latency between generation and reception of a message plus time to process the information.

Table 8. Summary of Alert Generation Performance

Vehicle	Speed	Alert Equation vs DVI	Alert Equation vs System Generation	Alert Equation vs Ground Truth
MDX	35 mph	4.26 m	2.78 m	1.41 m
	50 mph	2.95 m	0.96 m	3.76 m
	70 mph	9.82 m	6.91 m	5.47 m
Truck	35 mph	6.30 m	4.84 m	5.66 m
	50 mph	8.57 m	6.17 m	7.48 m
	60 mph	8.65 m	6.50 m	7.13 m

Table 9. Error Allowed in Distance Algorithm

Speed	Fixed Distance	Communication Latency (0.3 sec)	Processing Latency (0.085 sec)	Total Distance
35 mph	3.12 m	4.69 m	1.33 m	9.14 m
50 mph	3.12 m	6.70 m	1.90 m	11.72 m
60 mph	3.12 m	8.05 m	2.30 m	13.44 m
70 mph	3.12 m	9.39 m	2.70 m	15.17 m

System Warnings and Alerts

The following is a summary of the system performance where different factors were entered into the test to verify and validate system performance.

Several test cases were performed where the train preemption signal was issued after the CV had entered the approach. The purpose of these test was to understand the system performance and verification of the AASHTO Green Book Stopping Sight Distance formula used. The main objective was to validate if the Type A and C vehicles would have enough distance to reach a full stop prior to the stop bars when a train was detected later than usual. The vehicle speed during these tests was 50 mph. For the preemption activation at 3/4 mark and midpoint of the approach, both vehicles had ample time to travel down the approach lane, receive the warning and safely decelerate and come to a complete stop before reaching the stop bar. In the case of the preemption activation scenario at the at the 1/4 mark distance from the stop bar, as expected, both vehicles reached a full stop beyond the stop bar. See Figure 19.

A third scenario tested the light vehicle travelling at 70 mph and train preemption activation at the approach midpoint. The test was designed to understand the system performance with a higher vehicle speed and a late train preemption detection. The system issued a warning message at the expected location and provided ample time for a safe deceleration and came to a complete stop before reaching the stop bar.

For test case 2.4.4 the preemption signal was removed at midpoint after the vehicle had entered the approach. In this case, the system issued an HRI Active Inform Alert. The train preemption was removed before a warning message was deemed necessary, removing the inform alert and allowing the vehicle to travel across the HRI with no nuisance alerts.

Test case 2.1.1 demonstrated on three iterations that the system did not produce nuisance alerts when the train preemption was not active. The light vehicle entered and travelled down the approach and crossed the HRI while preemption was off without issuing any warnings or alerts as expected.

Test cases 2.2.1 and 2.2.6 were designed to test the performance of the system under high speeds. The tests were designed for both vehicles travelling down the approach at 70 mph with train preemption active. Due to the distance of landscape in advance of the length of the approach zone (ingress MAP lane), the Heavy Truck vehicle was not able to reach the 70 mph. As a result, it was decided to reduce the vehicle speed on the approach to 60 mph. The system was able to generate a warning at the proper distance and provide ample time for both vehicles to safely decelerate and come to a complete stop prior to reaching the stop bar.

Test case 2.5.1 was designed to test the proper issue of a special warning when a vehicle, after traversing the approach, stopped in the HRI Hazard Zone regardless of the state of the preemption. Thirty iterations were performed with train preemption off. On all iterations, the vehicle received the proper “Clear HRI” warning when remaining at a stop in the HRI Hazard Zone. The message cleared as soon as the vehicle started moving.

Test cases 2.6.5 and 2.6.6 tested the “Snap to Lane” functionality. This feature snaps a vehicle to the approach lane in the case its location deviates horizontally as a result of GNSS multipath effects or any other GNSS accuracy condition. To simulate this effect, the tests required the vehicle travel down the approach with preemption on and after it receives the warning message the driver swerved the vehicle one lane width to the right or the left, depending on the case. Three iterations of each test case were performed. On all iterations, the system effectively persisted issuing the approach warning while the vehicle swerved away from the lane. It was verified via TMX Core logs that the system detected this lane change and “snapped” the vehicle location to the correct lane.

Figure 19. 3/4 Mark, Midpoint and 1/4 Locations

Pavement Condition

The AASHTO Green Book Stopping Sight Distance formula used to issue a warning to a vehicle covers 90 percent of all drivers in both dry and wet conditions given current pavement, tire, and vehicle technologies. Several tests were designed where the pavement conditions would change from dry to wet to compare system performance and validate the use of the Green Book formula. Test cases 2.2.7, 2.2.8, 2.2.9 and

2.2.10 were designed to be identical to cases 2.2.1e, 2.2.1h, 2.2.3 and 2.2.5 respectively, with the difference being that the road was wet. Thirty iterations for each test case were conducted. The plan was to use a water pipe to periodically apply water on the test track for the duration of the tests. However, this was not needed since heavy rain took place during the day of testing. It was observed during these tests that wet pavement conditions do not have an impact on system performance. Both vehicles were able to safely decelerate after receiving the warning message and come to a complete stop before reaching the stop bar on all iterations.

Graded Course

Test case 2.3.1 was designed to have the system be put to test on a course with a grade higher than 0 percent. A -10 percent graded course located at TRC's facilities was used for this test. The location is surrounded by heavy tree foliage which had the potential to result in a degradation of the GNSS signal. The roadside unit was positioned next to the stop bar at the bottom of the course, resulting in the vehicle not having a direct line-of-sight for DSRC radio communications. Seven iterations of this test case were performed. Despite the location challenges, the system was able to maintain an RTK GNSS solution (fixed/float) throughout each of these iterations. Several System Fault alerts were issued when the vehicle was out of direct line-of-sight to the RBS (MAP Data not Received, SPaT Data not Received) as expected, but recovered immediately as the line-of-sight was established. Once the VBS system regained full functionality, the system was able to generate the proper alerts and warnings and the vehicle was able to safely decelerate and come to a complete stop before reaching the stop bar on all iterations.

System Stability When Near/In/Beyond the HRI

Three stationary stability tests when the test vehicle was near/in/beyond the HRI were conducted. These tests were conducted to confirm that a driver that stops along the boundary of the HRI Hazard Zone does not receive nuisance/intermittent warnings/lack of warnings (i.e., the GPS accuracy is sufficient for the VBS to reliably know where the vehicle is located relative to the HRI Hazard Zone boundaries, and this fix does not drift over a significant period). The test was performed for 10 minutes at each of the locations shown below:

a) Vehicle is located on the edge of the Approach Zone and the stop bar
b) Front of Vehicle is inside the HRI Hazard Zone
c) Entire Vehicle is beyond the HRI Hazard Zone

An issue was experienced during the performance of the first test (see Signal Bounce When Vehicle Reaches a Stop) this issue did not have an effect on the direct results of the test. No inappropriate warnings appeared each of the 10-minute periods. Similarly, the 'Clear HRI' warning did not cease to display over a 10-minute period with the vehicle positioned as specified in test iteration b). The RCVW system performed very well during the tests.

System Fault Verification

Specific test cases were designed and performed to verify and validate the different system faults the system is designed to recognize and inform the vehicle driver.

1. Loss of DSRC after the CV has received an RCVW
2. Loss of DSRC prior to the CV entering the MAP
3. Loss of RTK Fix / Degraded GNSS Solution
4. Loss of MAP
5. Loss of IEEE 1570 Heartbeat

The loss of DSRC was replicated by disabling the MessageReceiver plugin on the VBS after the issue of a warning message for case 1, and prior to the entrance of the vehicle to the approach for case 2. For the loss of RTK Fix/Degraded, the broadcast of RTCM corrections was disabled prior to the entrance of the vehicle to approach. For loss of MAP, the RBS MAP plugin was disabled. The loss of the IEEE 1570 Heartbeat was replicated by disconnecting the IEEE 1570 serial interface controller to the roadside CPU, effectively suspending the reception of the Heartbeat.

All test cases performed as expected. The system effectively issued a System Fault alert for all the conditions being tested

An issue was observed during the testing of loss of RTK fix. The RTK fix does not cease instantaneously after the loss of RTCM message reception. It was observed during testing that an RTK fix is retained for a few seconds after this occurs.

In addition to the RTK fix loss System Fault alert, the system is designed to issue a System Fault alert when the GPS position update rate falls below the configured threshold. This was validated across all test cases by reviewing the log files for each test case iteration. There were events where the update rate fell below the specified parameter and the system issued a system fault. However, these cases were sporadic and lasted a few milliseconds. See Issuing of System Faults.

DSRC Messaging and Data Processing Latency Requirement Verification

The following requirements are associated with the RCVW system latency. All requirements were verified and validated following the process described in the Paquet Capture Log Files Based Analysis.

- RBS 4 – The roadside-based subsystem shall broadcast the HRI Active message 10 times per second when an associated HRI controller activates a preemption signal.
- RBS 7 – The roadside-based subsystem shall broadcast the HRI Configuration Data Format (HCDF) once per second.

- RBS 21 – The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard.
- VBS 22 – The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms.
- VBS 23 – The vehicle-based subsystem shall be capable of processing received data within 85 ms.

An analysis of the log files from the RBS DSRC radio was performed to verify the following requirements

- [RBS-7] RBS broadcast the HCDF once per second
- [RBS-4] RBS broadcast the HRI Active message 10 times per second

Log data of 244 test runs was analyzed and for each, a rate of broadcasted SPaT and MAP data was calculated. The RBS broadcasted on average 510 SPaT messages and 45 MAP messages during each run with a rate of 1.021 MAP messages and 9.785 SPAT messages per second.

The smallest rate of MAP message broadcasted in a run was 1.01 messages per second and the largest was 1.05 messages per second. The smallest rate of SPaT messages broadcasted in a run was 9.6 messages per second and the largest was 9.8 messages per second. Figure 20 and Figure 21 show the distribution of the message rates for MAP and SPaT respectively.

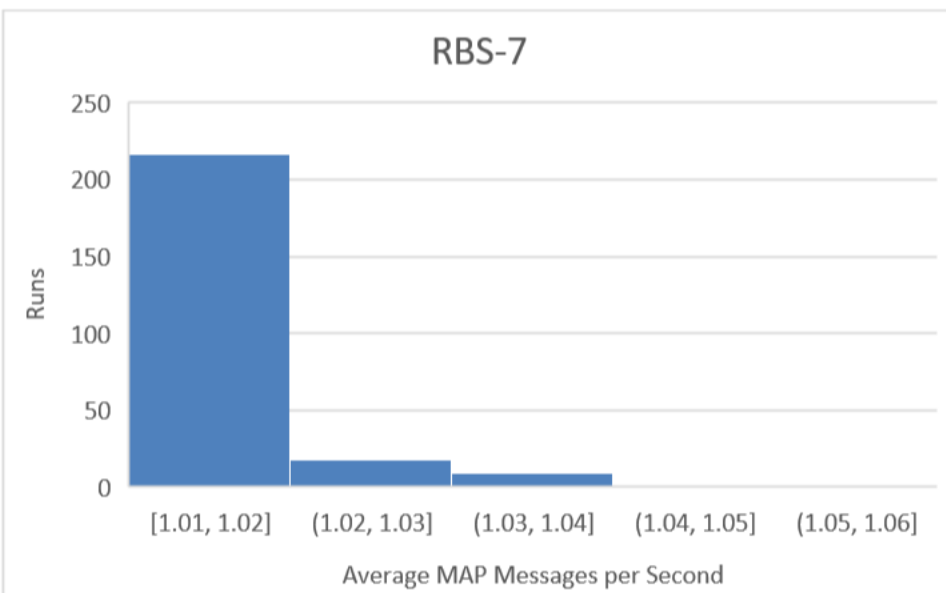


Figure 20. Average MAP Message Sent by the RBS Per Second

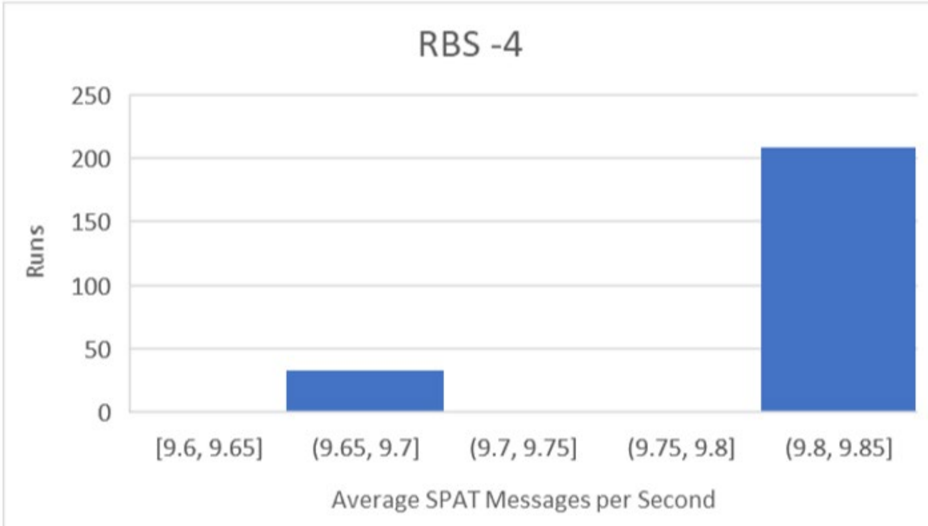


Figure 21. Average SPaT Message Sent by the RBS Per Second

While the analysis shows the system meets requirement RBS -7, it fails to meet requirement

RBS -4 by not achieving a rate of 10 SPAT messages per second.

VBS-22 requires the reception of roadside message within 50 ms after being sent. Two approaches were taken for this analysis. The first one focused on a latency analysis of the SPaT messages being sent and received, while the second looked at the MAP messages. This approach allows an analysis of the two main messages being exchanged by the two subsystems. A latency analysis for each message sent and received on 243 test runs was performed. SPaT message latency was analyzed for 126 runs, while 117 runs focused on MAP messages. The average message latency for the total 243 test runs was 0.0039 seconds, this includes MAP and SPaT messages, with 0.002 seconds being the smallest and 0.12 seconds the largest latency. When focusing the analysis on SPAT messages, the average total latency was 0.0032 seconds, with 0.003 being the smallest and 0.004 the largest latency. When analyzing the MAP message latency, the average total latency was 0.0047 seconds, with 0.002 being the smallest and 0.12 the largest latency. Figure 22, through Figure 24 show the distribution of the latency for these three different approaches. The graphic does not visibly present the message with latency of 0.12 seconds as it was only one on each run and it is too small to be displayed.

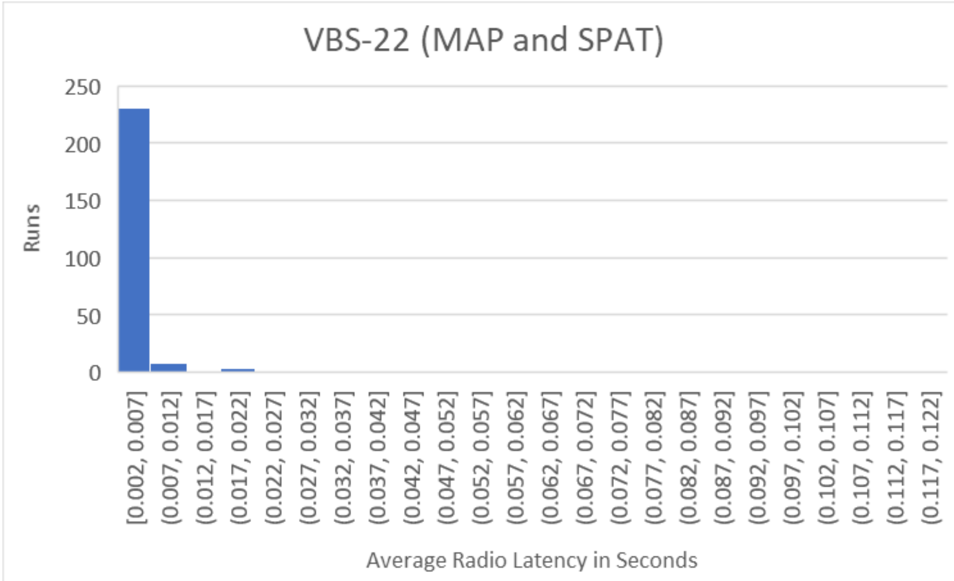


Figure 22. Combined MAP and SPaT Reception Latency

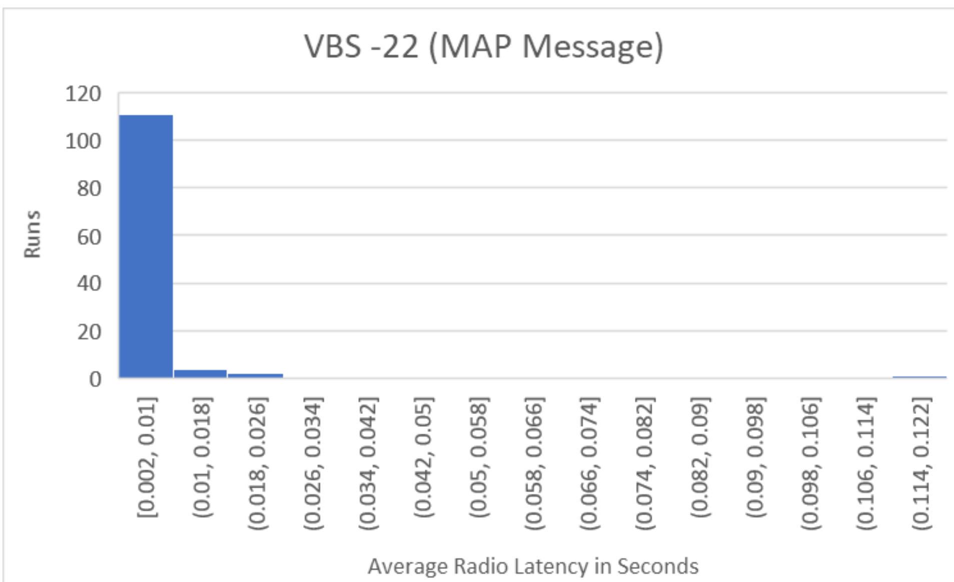


Figure 23. MAP Reception Latency

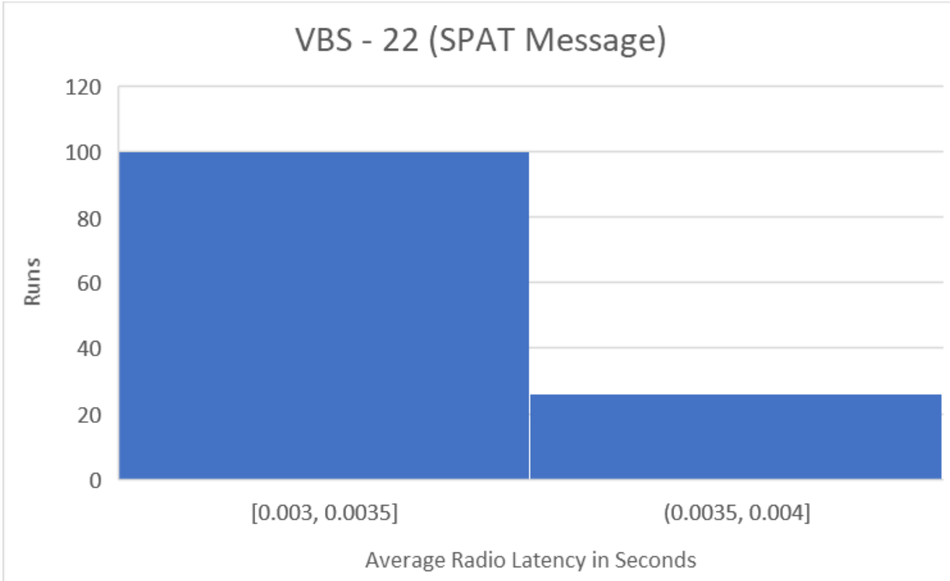


Figure 24. SPaT Reception Latency

When looking at the message latency at a run level, it can be observed that in all tests performed at least one of the runs presented messages exceeding the requirement of 50 ms latency. The highest number of messages observed in a test run with a latency of over 50 ms was 3. An example of this can be seen in Figure 25. The figure shows the chart for run number 5 of test 2.2.1e (Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions). In the chart it can be observed that from a total of 517 messages received, only 3 messages exceed the requirement.

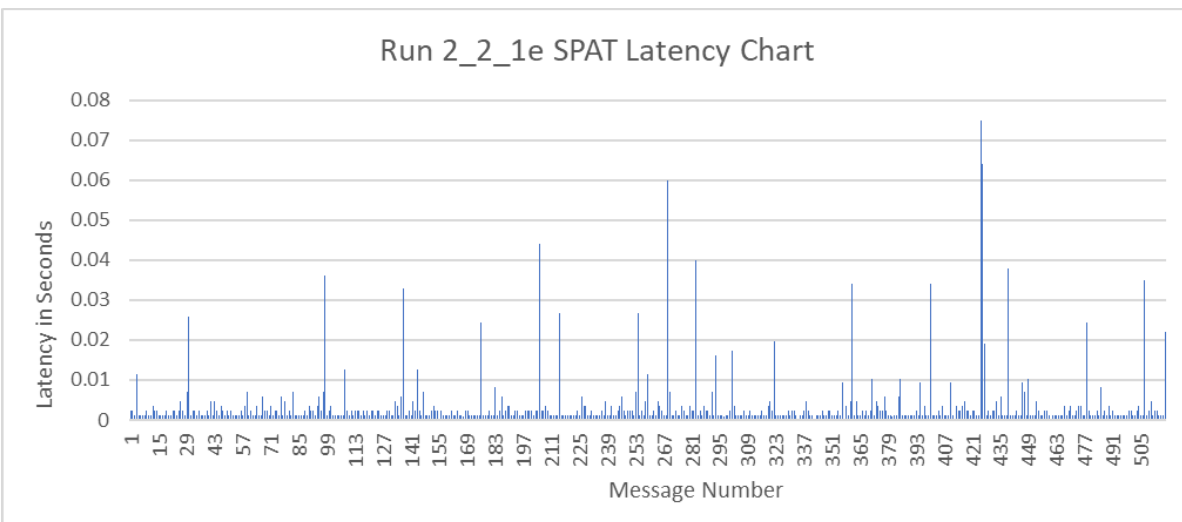


Figure 25. Run 5 2.2.1e Latency Chart

The average latency for this run is 0.0035 seconds. Figure 26 shows the distribution of the latency for this particular run.

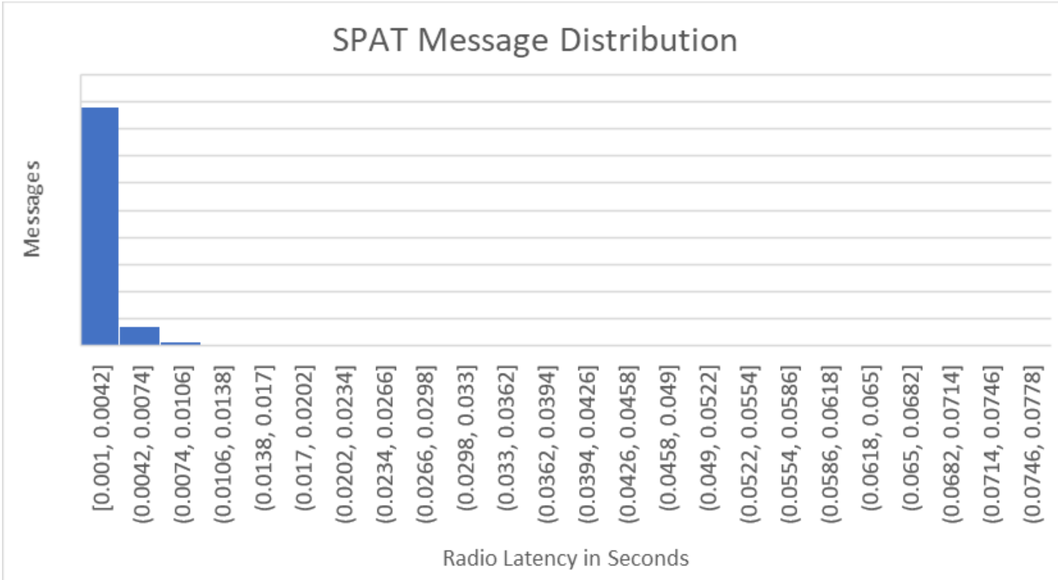


Figure 26. Run 5 2.2.1e SPaT Message Distribution

Figure 27 shows the latency chart for run number 8 of test 2.2.5 (Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions). It can be observed that 576 messages had a latency of under 50 ms.

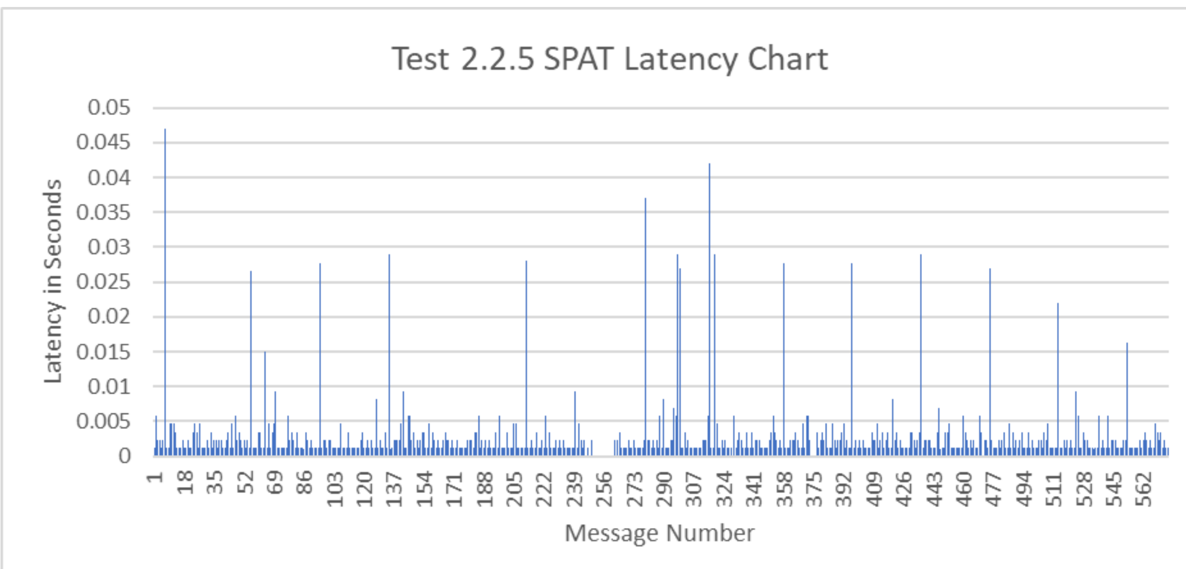


Figure 27. Rn 8 2.2.5 Latency Chart

The average latency for this run is 0.003 seconds. Figure 28 shows the distribution of the latency for this particular run.

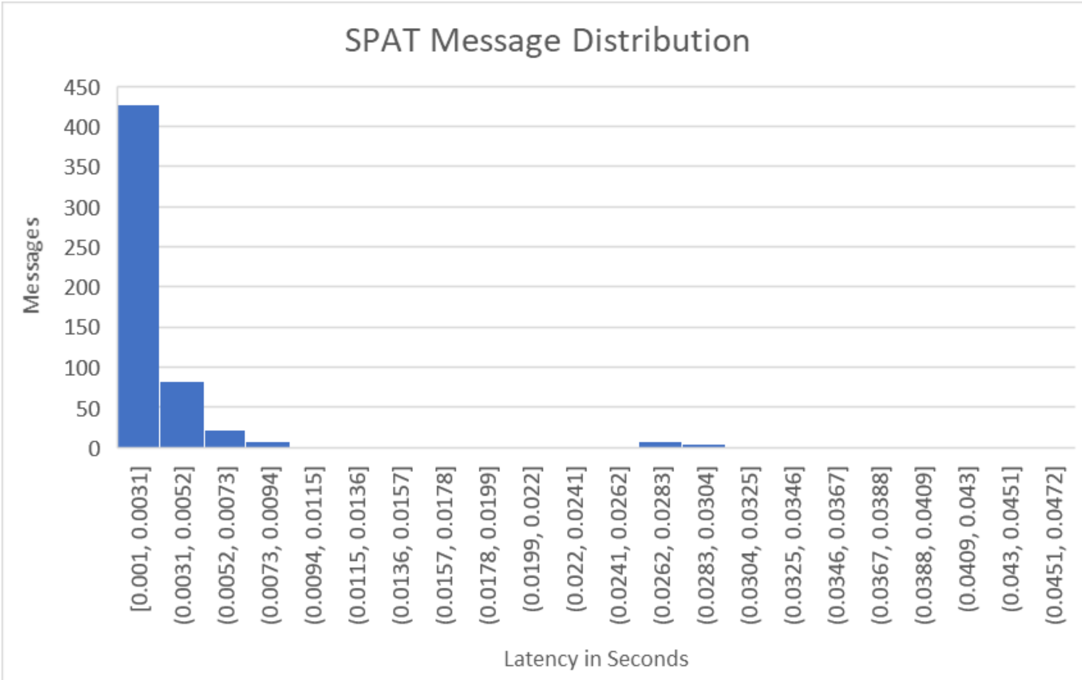


Figure 28. Run 5 2.2.5 SPaT Message Distribution

The results of the analysis show that the vehicle-based subsystem is capable of receiving messages sent by the roadside-based subsystem within 50 ms. During the field test period, the few cases where the latency exceeded the requirement did not have an effect on system performance as alerts and warnings were issued at the proper time.

VBS-23 requires the system to be capable of processing received data within 85 ms. The data received is directly processed by the RCVW plugin, this data comes asynchronously and is processed every time it receives a location (GNSS) message which is generated by the location plugin. The analysis to validate this requirement looks at the processing time between receiving a location message and generating an alert as a result of that message. 125 runs were analyzed by extracting the time when the RCVW log file indicates an alert was issued and the time the latest location message was received. The difference between these two times indicates how long it takes RCVW to fully process the data and generate an alert.

It is important to mention that the data from the field test log files does not provide an end-to-end latency analysis. To calculate this, additional bench tests are needed to determine the time required for the Location plugin to decode and process location information. Currently, the log files only provide the time the Location plugin delivers the already processed location data. Adding this to the processing time already described would provide a complete latency analysis (focused only on GPS processing time). One more thing to consider is that the system does not perform calculations when every piece of data arrives. This is because this data arrives asynchronously, and location data is considered the most important. MAP, SPaT, and VBM messages are cached when received and the last one of each is used when a location message is received.

Since location messages are received at ~10 Hz, it is possible that all the other cached data could be up to 100 ms. latent when calculations are performed.

The analysis of the runs shows that on average the processing time after a location message is received by the RCVW plugin is 0.012 seconds. The maximum latency observed was 0.033 seconds and the minimum was 0.0012 seconds. Figure 29 shows the distribution of the latency data for the 125 runs analyzed.

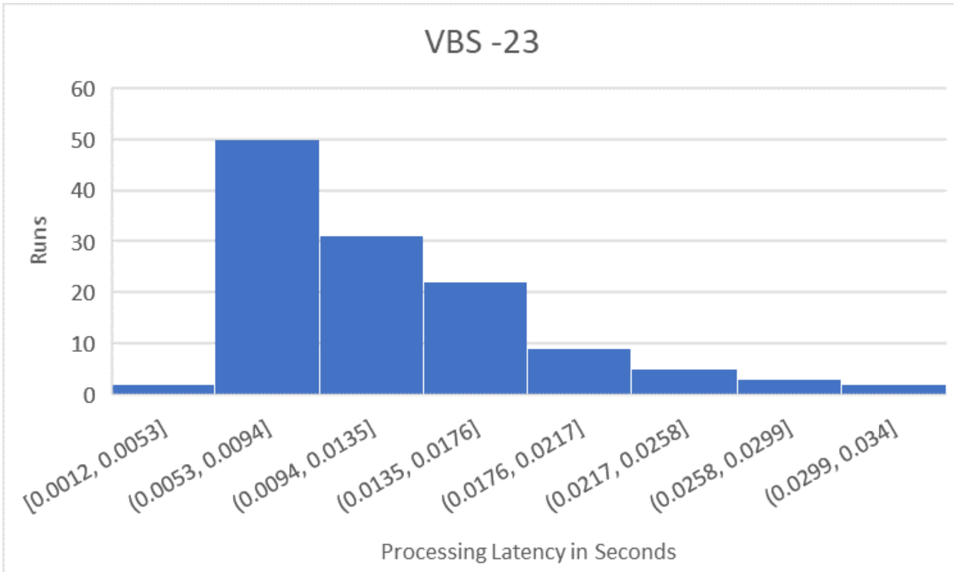


Figure 29. Processing Latency

The analysis shows that the processing latency for the 125 runs was well less than the 85 ms required by VBS-23.

Summary of Detected Issues and Anomalies and Potential Refinement

The following detected issues and anomalies, and potential refinement opportunities were identified during FT&E.

Heavy Truck Position Accuracy

Results from the position accuracy analysis of the Heavy Truck show an average longitudinal positional error of 4.13 m at 35 mph, 4.54 m at 50 mph, and 4.46 m at 60 mph. When compared with the errors from the Light Vehicle, it shows a discrepancy between system accuracy of around 3 m, generally fixed in the longitudinal direction. One hypothesis for what could cause such a large offset from the specification of the GNSS module could be the large metal overhang on the truck. After the antenna was raised and moved away from the overhang, there was a notable improvement in accuracy. However, the discrepancy with the light vehicle was not entirely eliminated.

Lane Shift

During the analysis of the RCVW log data, it was identified that several runs showed the vehicles had a large positional error (>2 m) in the lateral direction (see Figure 30). The “Snap to Lane” function was employed to identify the vehicle as shifting lanes and positioned its location correctly on the travelling lane. This avoided the issuance of a System Fault alert. Even when the log files show the system receiving GPS data at the correct rate and holding an RTK solution, the vehicle was not being positioned in an accurate location.

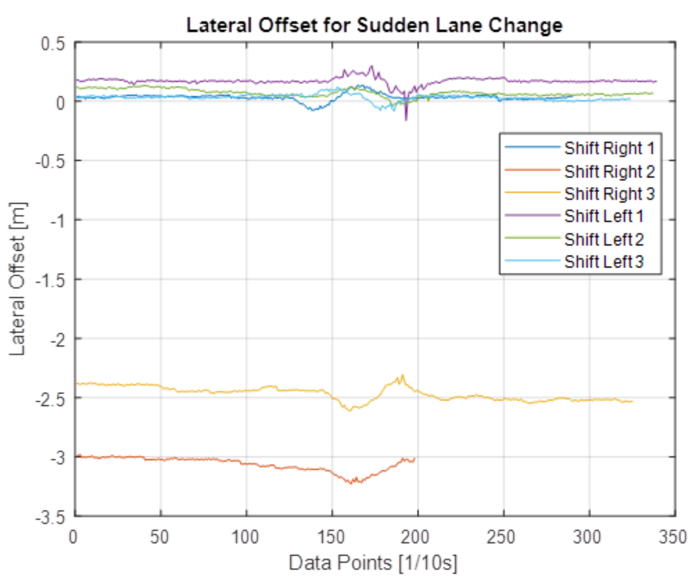


Figure 30. Sudden Lane Change

Verification of Requirement RBS-21

Requirement RBS–21 states the following:

The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard.

Requirement RBS-21 was originally verified during BT&E activities. During bench testing, it was observed that IEEE-1570 serial box's GPS time was not fully synchronized to the RCVW system clock. As a result, an accurate latency analysis was not possible. It was decided that the requirement was to be tested during field testing by incorporating the train preemption input signal used by the IEEE-1570 box to the RCVW system. This would allow for capture of the precise time the signal was issued, which could then be compared to the time the RCVW system received the indication of HRI Active by the IEEE-1570 box, resulting in the measurement of the processing latency of the IEEE-1570 system. A loop detector was planned to be used to detect the presence of the test vehicle and issue a signal to the IEEE-1570 device, thereby simulating the presence of a train. This signal was also going to be fed to the Digital Input/Output (DIO) port of the roadside CPU, effectively detecting when the preemption signal was sent to the IEEE-1570 box and for the duration of time needed by the RCVW system to detect the state change. Hardware malfunctions as a result of heavy rains precluded use of the loop detector system and as a result, the requirement was not verified during field test.

A subsequent bench test was performed at the Battelle headquarters. The RBS software was configured to accept and log the time when a train presence signal was detected. A wire coming from the train presence signal switch was connected to the DIO port of the RBS computer. This signal is also sent to the IEEE 1570 device. This allowed us to log using the RCVW clock the times the train presence signal was sent. This signal is controlled in the lab by the activation/deactivation of a switch. The next step was to log the time when the IEEE 1570 box sends a 4909 message (status message) to the RBS as a result of the reception of the train detection signal. The difference between these two times indicate the latency of the HRI message packets across the IEEE 1570 interface. Figure 31 shows the connections between the IEEE-1570 device and the RBS CPU.

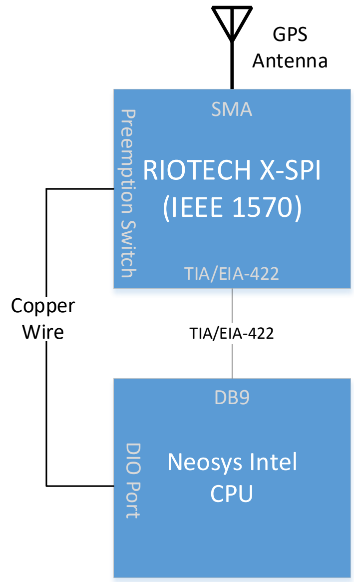


Figure 31. RBS-21 Requirement Verification Hardware Setup

Thirty iterations of this test were performed. Log files showed that the IEEE 1570 device issues two separate message when it detects a change in the HRI status. The issue of two messages is not part of the IEEE 1570 standard, but the result of configurable settings in the device. The first message has an average latency of 80 ms from the moment train presence signal is issued followed by a 200 ms latency before the actual “HRI Active” message from the IEEE 1570 device is received.

The analysis verifies that requirement RBS-21 is met. Data packets are in fact being received in less than 250 ms confirmed by the reception of the first 4904 message around 80 ms after the state change. However, due to the configuration programmed into the IEEE 1570 device, the RBS do not receive the actual HRI Active message until 280 ms after the train detection signal is issued.

CAN Communications

Several issues were experienced regarding CAN communications. During the first day of testing it was identified that CAN speed information received from the Heavy Truck was not being decoded correctly. This caused the Heavy Truck VBS issuing alerts and warnings earlier than predicted. As a result, GPS-based vehicle speed information was the only speed data included in the analysis.

Log file analysis showed that the VBM data (CAN) of the Acura vehicle often reported a non-zero speed even when the vehicle was at a complete stop. During several tests which required the vehicle to be at a complete stop, the VBM reported a speed of about 0.5 meter per second.

DSRC Signal Communications Gap

Throughout the 3 days of testing, it was observed that the Heavy Truck system experienced a 0.5 to 1.0 second loss of DSRC radio signal. At around the same location, the truck would enter the approach, issue the HRI Active Inform Alert, subsequently issue a System Fault alert, and an instant later re-issue Inform Alert. An analysis of the log files indicated that the roadside system was effectively sending the required messages and no problems were observed. However, it was observed in the log files that data packets were not being received at the mentioned locations, resulting in the issue of the System Fault alerts. Figure 32 shows the latency between sent and received SPaT messages for Test 2.2.2 Run 20.

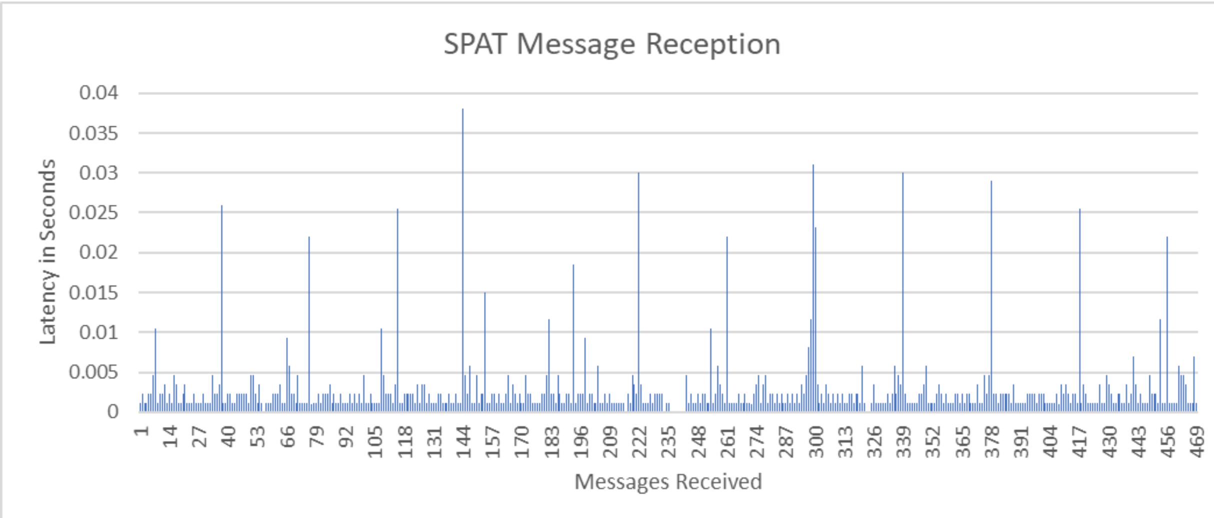


Figure 32. Test 2.2.3 Run 20 SPaT Message Reception

Around message 235 there is a gap in the reception of messages. The same phenomenon can be observed in Figure 33. Figure 34 represents the same issue only with the analysis based on the reception of MAP messages for Test 2.2.8 Run 10. In this case, the gap in reception can be observed around message 24.

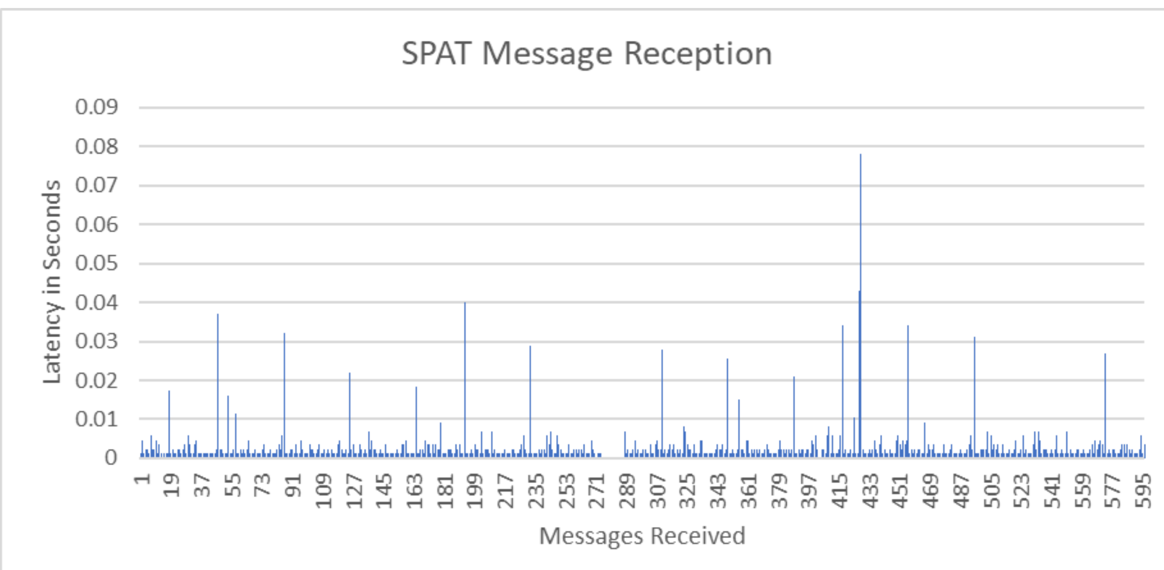


Figure 33. Test 2.2.5 Run 11 SPaT Message Reception

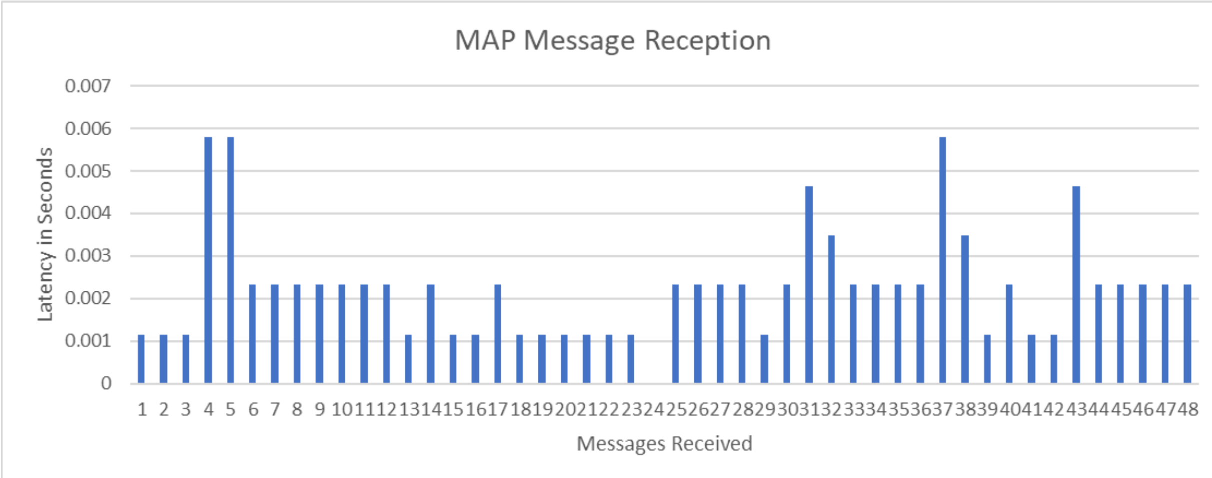


Figure 34. Test 2.2.8 Run 10 MAP Message Reception

Periodic DSRC Signal Latency Increase

As shown previously, DSRC signal latency was, on average, 0.004 seconds. However, during the log data analysis, a periodic DSRC message latency increase of 0.02 seconds was observed every four to 5 seconds. This periodic behavior is shown in Figure 35. The phenomenon was observed in field testing of the Heavy Truck and Light Vehicle RCVW systems.

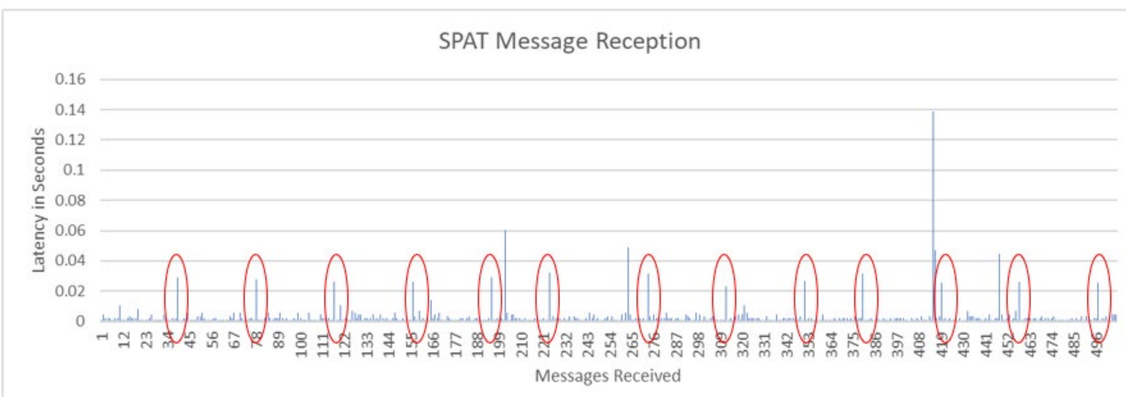


Figure 35. Test 2.2.1e Run 10 Periodic Signal Latency Increase

Signal Bounce When Vehicle Reaches a Stop

This issue was first observed during a series of parking lot tests. As the vehicle reaches a full stop, it sometimes rocks back and forth as a result of the inertial forces applied to the vehicle's shock absorbers and the subsequent restorative forces applied to maintain equilibrium. The system identifies this minor movement as the vehicle driving in an opposite heading and extinguishes all alerts or warnings. Code was implemented where the system filters out these oscillations. As a result, the system ignores a maximum of seven oscillating points and locks GPS speed to zero. Once the vehicle proceeds to move, filters out the first seven points (to ensure that the vehicle is in fact moving) and proceeds to use the updated heading from the GPS. This solution was successfully implemented and tested.

A similar issue was observed during field testing activities. After an analysis of the log files, it was identified that the issue was a result of speed information being received via the CAN interface while the vehicle was stationary. The vehicle approached the HRI and received an Alert message as a result of train preemption being active. When the vehicle stopped, it bounced for a short period of time and eventually arrived at a heading that was greater than 45 degrees. Since the speed was locked to zero (due to the implemented code), RCVW ignored this heading and retained the value prior to the bouncing and as expected, the Alert message remained. About 2 seconds later VBM data started reporting a vehicle speed of about 0.5 m/s. (with the vehicle still stationary). Since vehicle speed was no longer zero (based on VBM data), RCVW started processing data again. The system filtered the first seven points, but vehicle heading is never updated since the GPS is not registering any movement, so the system used the last heading recorded in the system (heading >45 degrees). This resulted in the system assuming the vehicle is travelling on an opposite direction incorrectly clearing any alerts or warnings.

Processor Lag

After a few hours of continuous usage, the RCWV plugin experienced a delay in processing the Location Messages, resulting in a low data frequency fault. During field test activities and between tests, the RCVW plugin was restarted every 3 hours to reset the processor memory. After the reset, the system resumed normal operations and all processing delays cleared.

Configuration Issues

The following issues occurred during field testing as a result of wrong configuration of the system.

- 90% of the RCVW logs for the Heavy Truck for day one were overwritten.
- Pop ups on the Heavy Truck System DVI were observed
- Heavy Truck system hardware required a manual start

All issues have been identified and corrected. A Standard Operating Procedure is being produced which will detail the correct configuration procedures for the RCVW system. This document will be delivered as part of the project deliveries.

Issuing of System Faults

Every test run during FT&E activities experienced the issuing of a System Fault alert, such as Loss of SPaT, Loss of MAP and Low GPS Frequency. However, system performance was not affected by these losses. It was observed by the vehicle driver and later confirmed via log analysis, that the system was able to recover extremely quickly after the issuing of these messages and continued to issue the proper alerts and warnings. A deeper analysis and assessment needs to be performed to evaluate if the system settings can be modified to reduce the number of fault messages.

Dilemma Zone

There were a series of test cases where the train preemption was activated once the vehicles were positioned on the 1/4 distance to the stop bar. All these cases experienced the vehicle not being able to come to a full stop prior to reaching the stop bar and in some cases stopping on the HRI Further analysis is required to determine the threshold distance from the stop bar at which no RCVW should be issued. The factors to determine the threshold include current position, vehicle speed, HRI design, grade, vehicle type.

Braking Robot Deceleration Rate

It was noted during the first day of testing that the deceleration rate of the Heavy Truck was not as expected. The robot was programed to perform a deceleration rate of 2.67 m/s2 (0.27 g). In reality, the deceleration rate of the robot varied from 0.22 to 0.25 g. The reason is that the robot is not designed to work with braking systems such as the one equipped in the Volvo Truck, as a result, the Truck was consistently coming to a full stop beyond the stop bar. The braking rate was adjusted for the rest of the cases and the Heavy Truck was able to reach a full stop before reaching the stop bar.

Detailed RCVW Field Test & Evaluation Results

The objective of the verification testing comprising the RCVW FT&E Plan was to verify and demonstrate that the RCVW system possesses the functionality and performance necessary to deliver the functions and benefits proposed for the system described in the RCVW Concept of Operations [1] in an operational setting. FT&E testing also aimed to verify that the RCVW system meets the requirements documented in the System Requirements Specification [2]. The following pages of this section detail the results of each test case and includes noted observations.

Test Case No. and Title	**2.1.1. Type A CV Approaches and Travels through HRI with no Train Approaching, 50 mph – No HRI Active Signal**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** Confirm that an RCVW is NOT displayed/annunciated while the CV is within the Approach and HRI zones • Confirm that a System Ready is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that a System Available is displayed while the CV is entering or departing from the HRI • Confirm that a System Ready is displayed once the CV has departed the HRI **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is not active
Requirements Verified	**RCVW-8** **VBS-5, 6, 10, 22, 23** **RBS-5, 7, 21, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is not generated because a train has not been detected (i.e., a preempt call has not been placed) by the highway rail grade crossing train detection system. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Not Active for the duration of this test • The initial approach speed of the CV shall be 50 mph • Pavement surface condition is dry • The status of the RCVW system is “Normal”

Test Case No. and Title	**2.1.1. Type A CV Approaches and Travels through HRI with no Train Approaching, 50 mph – No HRI Active Signal**	
	• This test will be performed using a passenger car (type A) The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC)	
Verification Phase	**II – Field Test Verification**	
	• Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated	
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets	
Pass/Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)	Date: 10/29/2020

Test Case No. and Title			**2.1.1. Type A CV Approaches and Travels through HRI with no Train Approaching, 50 mph – No HRI Active Signal**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
An RCVW is not displayed/annunciated while the CV is within the approach and no preemption is detected [RCVW-8] [VBS-6] [VBS-10] [RBS-5].			
A System Ready is displayed while the CV is outside of the approach zone [VBS-10].			
A System Available is displayed while the CV is moving across the HRI [VBS-10].			
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].			
RBS stop broadcasting the HRI Active message when no preemption is detected [RBS-5].			
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms.[VBS-22].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall be capable of processing received data within 85 ms [VBS-23]	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.

Test Case No. and Title	**2.1.1. Type A CV Approaches and Travels through HRI with no Train Approaching, 50 mph – No HRI Active Signal**		
Verification Phase	**II – Field Test Verification**		
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard [RBS-21].	**N/A**	**N/A**	Train preemption was off per test design. No IEEE 1570 messages were being processed.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• One test case failed due to Camera (Test Equipment) malfunction. • A total of three successful test cases were performed. • The Roadside Plugin needed to be restarted to eliminate processor lags. See Processor Lag.

Test Case No and Title	2.2.1e Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions
Verification Phase	II – Field Test Verification
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Active graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20, 22, 23** **RBS-4, 7, 21, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW

Test Case No and Title	2.2.1e Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions
Verification Phase	**II – Field Test Verification**
	predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis. This Test Case is similar to Test Case 2.2.1h, except the vehicle speed changes from 50 mph to 35 mph
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test • The initial approach speed of the CV shall be 50 mph • Pavement surface condition is dry • The status of the RCVW system is "Normal" • This test will be performed using a passenger car (type A) The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. • Results will be compared with 2.2.1h to contrast the impact of the vehicle speed,

Test Case No and Title	**2.2.1e Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Case No. and Title	**2.2.1e Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**
Verification Phase	**II – Field Test Verifications**
Pass/Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results) — Date:10/28/2020

Test Case No and Title			**2.2.1e Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**
Verification Phase			**II – Field Test Verifications**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		

Test Case No and Title	**2.2.1e Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**		
Verification Phase	**II – Field Test Verifications**		
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms [VBS-22].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall be capable of processing received data within 85 ms [VBS-23].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard [RBS-21].	**N/A**	**N/A**	See Verification of Requirement RBS-21
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• Several Faults were raised during testing. See Issuing of System Faults for more information on this issue. • Vehicle stopped where researchers predicted

Test Case No. and Title	**2.2.1h Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20, 22, 23** **RBS-4, 7, 21, 22**

Test Case No. and Title	**2.2.1h Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.	
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test • The initial approach speed of the CV shall be 50 mph • Pavement surface condition is dry • The status of the RCVW system is "Normal" • This test will be performed using a passenger car (Type A) The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated	
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:10/28/2020

Test Case No. and Title	2.2.1h Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions		
Verification Phase	**II – Field Test Verification**		
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		Run 17, 25 and 27 experienced the RCVW cleared, re-issued and cleared once again after 100 ms for run 17, 108 ms for run 25 and 87 ms on run 27. The system performed as expected the rest of the runs.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test

Test Case No. and Title	**2.2.1h Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**		
Verification Phase	**II – Field Test Verification**		
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms [VBS-22].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall be capable of processing received data within 85 ms [VBS-23].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard [RBS-21].		**N**	See Verification of Requirement RBS-21
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag • Vehicle stopped where we had predicted • Several Faults were raised during testing. See Issuing of System Faults

Test Case No. and Title	**2.2.1l Type A CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20, 22, 23** **RBS-4, 7, 21, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI.

Test Case No. and Title	**2.2.1l Type A CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	This Test Case is similar to Test Case 2.2.1h, except the vehicle speed changes from 50 mph to 70 mph 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test • The initial approach speed of the CV shall be 50 mph • Pavement surface condition is dry • The status of the RCVW system is “Normal” • This test will be performed using a passenger car (type A) The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case • Results will be compared with 2.2.1h to contrast the impact of the vehicle type
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results) Date:10/30/2020

Test Case No. and Title			2.2.1l Type A CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		Run 1 and 2 experienced the RCVW cleared and re-issued after 509 ms for run 1 and 308 ms on run 2. The system performed as expected for the rest of the runs.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test

Test Case No. and Title			2.2.1l Type A CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VB.S-5].		**N**	See Positional Accuracy for more information
The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms [VBS-22].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall be capable of processing received data within 85 ms [VBS-23].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard [RBS-21].		**N**	See Verification of Requirement RBS-21
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• Several Fault Messages were issued during testing. See Issuing of System Faults

Test Case No. and Title	**2.2.3 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that The RCVW is no

Test Case No. and Title	**2.2.3 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis. This Test Case is similar to Test Case 2.2.1h, except the vehicle type changes from A (car) to C (heavy truck) which results in a change on the deceleration rate.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test • The initial approach speed of the CV shall be 50 mph • Pavement surface condition is dry • The status of the RCVW system is “Normal” • This test will be performed using a Heavy Truck (type C) The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case • Results will be compared with 2.2.1h to contrast the impact of the vehicle type.

Test Case No. and Title	**2.2.3 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/28/2020

Test Case No. and Title			**2.2.3 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		RCVW Log files were not available for analysis for this test runs. Validation is based on Observation and data from TRC analysis equipment. See Configuration Issues.
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		RCVW Log files were not available for analysis for this test runs. Validation is based on Observation and data from TRC analysis equipment. See Configuration Issues.
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4]	**Y**		RCVW Log files were not available for analysis for this test runs. Validation is based on Observation and data from TRC analysis equipment. See Configuration Issues.

Test Case No. and Title			**2.2.3 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		RCVW Log files were not available for analysis for this test runs. Validation is based on Observation and data from TRC analysis equipment. See Configuration Issues.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test.
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		

Test Case No. and Title			**2.2.3 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
Notes			• Several Fault Messages were issued during testing as a result of processor lags. The RCVW Plugin needed to be restarted to eliminate this issue. See Processor Lag. • CAN data was being fed to the system to perform calculations. The data was decoded incorrectly by the system and was decided to be disabled, see CAN Communications. • The braking robot was using a deceleration rate slower than desired. See Braking Robot Deceleration Rate. • All Heavy Truck runs experience a SPAT Data Not Received error at the exact same location. See section DSRC Signal Communications Gap. • On run 25, the bounce effect described in section Signal Bounce When Vehicle Reaches a Stop is present.

Test Case No. and Title	**2.2.5 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer

Test Case No. and Title	2.2.5 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions
Verification Phase	II – Field Test Verification
	generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis. This Test Case is similar to Test Case 2.2.1e, except the vehicle type changes from A (car) to C (heavy truck) which results in a change on the deceleration rate.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test • The initial approach speed of the CV shall be 50 mph • Pavement surface condition is dry • The status of the RCVW system is “Normal” • This test will be performed using a Heavy Truck (type C) The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. • Results will be compared with 2.2.1e to contrast the impact of the vehicle type.

Test Case No. and Title	**2.2.5 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:10/28/2020

Test Case No. and Title			**2.2.5 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		RCVW Log files were not available for analysis for runs 1 to 23. Validation for these runs were based on Observation and data from TRC analysis equipment. See Configuration Issues.
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		RCVW Log files were not available for analysis for runs 1 to 23. Validation for these runs were based on Observation and data from TRC analysis equipment. See Configuration Issues.
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver	**Y**		RCVW Log files were not available for analysis for runs 1 to 23. Validation for these runs were based on Observation and data from TRC analysis equipment. See Configuration Issues.

Test Case No. and Title			2.2.5 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	Y		RCVW Log files were not available for analysis for runs 1 to 23. Validation for these runs were based on Observation and data from TRC analysis equipment. See Configuration Issues.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	Y		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		N	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		N	See Positional Accuracy for more information.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	Y		

Test Case No. and Title			**2.2.5 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
Notes			• The RCVW Plugin needed to be restarted to eliminate processor lags. See Processor Lag.

Test Case No. and Title	**2.2.6 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI.

Test Case No. and Title	**2.2.6 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	This Test Case is similar to Test Case 2.2.1I, except the vehicle type changes from A (car) to C (heavy truck), which results in a change on the deceleration rate. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.	
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status is Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is “Normal.” • This test will be performed using a Heavy Truck (type C). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated	
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case • Results will be compared with 2.2.1I to contrast the impact of the vehicle type.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:10/30/2020

Test Case No. and Title			2.2.6 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test.
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test.

Test Case No. and Title			2.2.6 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 70 mph, Dry Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		N	See Positional Accuracy for more information.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	Y		
Notes			• The RCVW plugin needed to be restarted to eliminate processor lags. See Processor Lag.

Test Case No. and Title	2.2.7 Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results • Confirm that the system is able to operate and perform in all weather and road conditions **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20, 22, 23** **RBS-4, 7, 21, 22**

Test Case No. and Title	**2.2.7 Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. This Test Case is similar to Test Case 2.2.1h, except the road conditions change from Dry to Wet. The test will demonstrate the system is able to operate and perform in all weather and road conditions. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status of Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is wet. • The status of the RCVW system is “Normal.” • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.

Test Case No. and Title	**2.2.7 Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**	
Verification Phase	**II – Field Test Verification**	
	• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with 2.2.1h to contrast the impact of the road conditions.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:10/29/2020

Test Case No. and Title			**2.2.7 Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-	**Y**		

Test Case No. and Title			**2.2.7 Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms [VBS-22].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall be capable of processing received data within 85 ms [VBS-23].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less		**N**	See Verification of Requirement RBS-21.

Test Case No. and Title			2.2.7 Type A CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
than 250 ms conforming to the IEEE 1570 standard [RBS-21].			
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• Log files show the vehicle was not in lane, see Lane Shift. • RCVW Plugin and the DSRC radio needed to be restarted to eliminate processor lags. See Processor Lag.

Test Case No. and Title	**2.2.8 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results • Confirm that the system is able to operate and perform in all weather and road conditions **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 7, 22**

Test Case No. and Title	**2.2.8 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. This test case is similar to Test Case 2.2.3, except the road conditions change from Dry to Wet. The test will demonstrate the system is able to operate and perform in all weather and road conditions. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is wet. • The status of the RCVW system is “Normal.” • This test will be performed using a Heavy Truck (type C). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.

Test Case No. and Title	**2.2.8 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**	
Verification Phase	**II – Field Test Verification**	
	• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.3 to contrast the impact of the road conditions.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:10/29/2020

Test Case No. and Title			**2.2.8 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16]	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-	**Y**		The power cable to the DVI was loose which resulted in the breaking robot not activating for some runs.

Test Case No. and Title			**2.2.8 Type C CV Approaches with Preemption Signal Detected at Approach Entry, 50 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5.]		**N**	See Positional Accuracy section for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• An issue with the power connector to the screen was identified • TRCs camera had issues on runs 26 and 29 resulting in driver activating the brakes • The RCVW Plugin needed to be restarted to eliminate processor lags. See Processor Lag.

Test Case No. and Title	**2.2.9. Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Active graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results • Confirm that the system is able to operate and perform in all weather and road conditions **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20, 22, 23** **RBS-4, 7, 21, 22**

Test Case No. and Title	**2.2.9. Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis. This test case is similar to Test Case 2.2.1e except the road conditions change from Dry to Wet. The test will demonstrate the system is able to operate and perform in all weather and road conditions.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status of Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is wet. • The status of the RCVW system is “Normal.” • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case • Results will be compared with 2.2.1e to contrast the impact of the road conditions.

Test Case No. and Title	**2.2.9. Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**	
Verification Phase	**II – Field Test Verification**	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/29/2020

Test Case No. and Title			**2.2.9. Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		On run 6 and 16, the bounce effect described in section Signal Bounce When Vehicle Reaches a Stop is present.
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		

Test Case No. and Title			2.2.9. Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms [VBS-22].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The vehicle-based subsystem shall be capable of processing received data within 85 ms [VBS-23].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE 1570 standard [RBS-21].		**N**	See Verification of Requirement RBS-21.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		

Test Case No. and Title			**2.2.9. Type A CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
Notes			• There are several runs where the system does not receive any errors • Several Fault Messages were issued during testing. See Issuing of System Faults • On run 6 and 16, the bounce effect described in Signal Bounce When Vehicle Reaches a Stop is present.

Test Case No. and Title	**2.2.10. Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available graphic is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results • Confirm that the system is able to operate and perform in all weather and road conditions **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 7**

Test Case No. and Title	**2.2.10. Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action (CV decelerates) to permit safe stoppage prior to the HRI. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis. This test case is similar to Test Case 2.2.5 except the road conditions change from Dry to Wet. The test will demonstrate the system is able to operate and perform in all weather and road conditions.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status Active for the duration of this test • The initial approach speed of the CV shall be 35 mph • Pavement surface condition is wet. • The status of the RCVW system is “Normal” • This test will be performed using a Heavy Truck (type C). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.

Test Case No. and Title	**2.2.10. Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**	
Verification Phase	**II – Field Test Verification**	
	• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case Results will be compared with 2.2.5 to contrast the impact of the road conditions.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:

Test Case No. and Title			**2.2.10. Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		

Test Case No. and Title			**2.2.10. Type C CV Approaches with Preemption Signal Detected at Approach Entry, 35 mph, Wet Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on how this requirement was validated.
RBS broadcasts the HRI Active message 10 times per second [RBS-4]		**N**	See Verification of Requirement RBS-21.
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• Log files show the vehicle was not in lane in several runs, see Lane Shift. • The bounce effect described in Signal Bounce When Vehicle Reaches a Stop is present in several runs. • Several Fault Messages were issued during testing. See Issuing of System Faults.

Test Case No. and Title	**2.3.1 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Road Grade -10%, 35 mph**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that a System Available is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI and there is an active Preemption signal • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action, there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted • Confirm that a System Available is displayed while the CV is in or departing from the HRI (if applicable) **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by road grade • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8,** **VBS-1, 3a, 3b, 3c, 4, 5, 6, 7, 10, 11b,11c, 12, 13, 14, 15, 16, 17, 20** **RBS-4, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. By varying the values of the road grade, the test will determine the limitations of the RCVW system and its algorithm.

Test Case No. and Title	**2.3.1 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Road Grade -10%, 35 mph**	
Verification Phase	**II – Field Test Verification**	
	This test case is similar to Test Case 2.2.1h except the road grade is -10%.	
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status is Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is "Normal." • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated	
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The Test Administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			2.3.1 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Road Grade -10%, 35 mph
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test

Test Case No. and Title			**2.3.1 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Road Grade -10%, 35 mph**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy section for more information.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• Several Fault Messages were issued during testing. See Issuing of System Faults • RTK Fix was achieved during all runs.

Test Case No. and Title	**2.4.1 Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active.

<table>
<tr><td>Test Case No. and Title</td><td>2.4.1 Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions</td></tr>
<tr><td>Verification Phase</td><td>II – Field Test Verification</td></tr>
<tr><td>Requirements Verified</td><td>RCVW-8
VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20
RBS-4, 5, 7, 22</td></tr>
<tr><td>Brief Description</td><td>The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI.

This test case is similar to Test Case 2.4.2 except that the preemption detection becomes active when the CV is within the Approach Zone at a point 3/4 the distance of the zone (based on initial approach entry speed), rather than at entry into the Approach Zone.

3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.</td></tr>
<tr><td>Test Setup and Configuration</td><td>Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test:
HRI status is Active for the duration of this test.
The initial approach speed of the CV shall be 50 mph.
Pavement surface condition is dry.
The status of the RCVW system is “Normal.”
This test will be performed using a passenger car (type A).
The following configuration states should be verified prior to test execution:
Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC)
Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast)
CV Inspector is running
Logging is activated</td></tr>
<tr><td>Test Procedure/Script</td><td>Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above.
After the test the following shall be performed:</td></tr>
</table>

Test Case No. and Title	**2.4.1 Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	• The loop detector is positioned at the ¾ approach point and is connected to the RIOTECH X-Spi Box. • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.4.1 Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is	**Y**		

Test Case No. and Title			**2.4.1 Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].			
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test.
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test.
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK	**Y**		

Test Case No. and Title			2.4.1 Type A CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
corrections using the RTCM messaging protocol [RBS-22].			
Notes			• The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. • Several Fault Messages were issued during testing. See Issuing of System Faults

Test Case No. and Title	**2.4.2 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 5, 7**

Test Case No. and Title	**2.4.2 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This Test Case is similar to Test Case 2.2.1h, except that the Preemption Signal detection becomes active when the CV is within the Approach Zone at a point 1/2 the distance of the Approach zone (based on initial approach entry speed), rather than at entry into the Approach Zone. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status is Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is "Normal." • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box.

Test Case No. and Title	**2.4.2 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	• The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date:10/30/2020

Test Case No. and Title			**2.4.2 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase			**II – Field Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted. [RCVW-8]	**Y**		

Test Case No. and Title			2.4.2 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions
Verification Phase			**II – Field Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17]			
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		

Test Case No. and Title			**2.4.2 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase			**II – Field Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
Notes			• The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. • One test run had to be dropped due to RTK issues. • No errors were present in this test.

Test Case No. and Title	**2.4.3a Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 5, 7**

Test Case No. and Title	**2.4.3a Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This test case is similar to Test Case 2.4.2 Iteration #1, except that the preemption detection becomes active when the CV is within the Approach Zone at a point near the transition from the Approach Zone to the HRI Zone (approximately 90% of the distance of the approach zone based on initial approach entry speed), rather than at entry into the Approach Zone. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • Train detected by the HRIC when the CV is at the 90% Approach Zone point. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is “Normal.” • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box.

Test Case No. and Title	**2.4.3a Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	• the administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • the administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.4.3a Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Transition, 50 mph, Dry Condition**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted. [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4]	**Y**		

Test Case No. and Title			2.4.3a Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Transition, 50 mph, Dry Condition
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].			
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		

Test Case No. and Title			**2.4.3a Type A CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Transition, 50 mph, Dry Condition**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
Notes			• The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. • Vehicle ending its runs located on top of the HRI. See Dilemma Zone. • Several Fault Messages were issued during testing. See Issuing of System Faults.

Test Case No. and Title	**2.4.3b Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 5, 7, 22**

Test Case No. and Title	**2.4.3b Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This test case is similar to Test Case 2.4.2, except that the preemption detection becomes active when the CV is within the Approach Zone at a point near the transition from the Approach Zone to the HRI Zone (approximately 90% of the distance of the approach zone based on initial approach entry speed), rather than at entry into the Approach Zone and the vehicle type changes from A (car) to C (heavy truck) which results in a change on the deceleration rate. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • Train detected by the HRIC when the CV is at the 90% Approach Zone point. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is "Normal." • This test will be performed using a Heavy Truck (type C). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box.

Test Case No. and Title	2.4.3b Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Conditions
Verification Phase	II – Field Test Verification
	• The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected

Test Case No. and Title			2.4.3b Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Condition
Verification Phase			II – Field Test Verification
Expected Results [requirement]	Met?		Notes
	Y	N	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	Y		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].	Y		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	Y		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI	Y		

Test Case No. and Title			2.4.3b Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Condition
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test.
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test.
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. • Vehicle ending its runs located on top of the HRI. See Dilemma Zone.

Test Case No. and Title			**2.4.3b Type C CV Approaches with Preemption Signal Detected near the Approach Zone Hazard Zone Transition, 50 mph, Dry Condition**
Verification Phase			**II – Field Test Verification**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
			• In this test the Heavy Truck did not experience any SPaT errors.

Test Case No. and Title	**2.4.4 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Preemption Signal is Removed at Midpoint, 50 mph, Dry Condition**
Verification Phase	**II – Field Test**
Test Objectives	**Primary Objectives:** • Confirm that a System Ready is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of the Preemption signal removed • Confirm that an Informed Alert reapers while the CV remains in the Approach Zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is not active
Requirements Verified	**RCVW-8,** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 5, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer issued once the Preemption signal is no longer present.

<table>
<tr><td>Test Case No. and Title</td><td colspan="2">2.4.4 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Preemption Signal is Removed at Midpoint, 50 mph, Dry Condition</td></tr>
<tr><td>Verification Phase</td><td colspan="2">II – Field Test</td></tr>
<tr><td></td><td colspan="2">3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.</td></tr>
<tr><td>Test Setup and Configuration</td><td colspan="2">Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test:
• Train detected by the HRIC at/prior to CV Approach Zone entry.
• The initial approach speed of the CV shall be 50 mph.
• Pavement surface condition is dry.
• The status of the RCVW system is “Normal” (until the Approach Zone midpoint).
• At the Approach Zone midpoint, HRIC communications are temporarily terminated by disconnecting the preemption signal connection to the RBS computing platform.
• This test will be performed using a passenger car (type A).
• No driver response, the vehicle is to advance through the HRI.
The following configuration states should be verified prior to test execution:
• Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC)
• Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast)
• CV Inspector is running
• Logging is activated</td></tr>
<tr><td>Test Procedure/Script</td><td colspan="2">Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above.
After the test the following shall be performed:
• The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box.
• The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.
• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case.
After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets</td></tr>
<tr><td>Pass / Fail</td><td>☐ Pass (met all expected results)
☒ Fail (did not meet one or more expected results)</td><td>Date: 10/30/2020</td></tr>
</table>

Test Case No. and Title			**2.4.4 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Preemption Signal is Removed at Midpoint, 50 mph, Dry Condition**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed while the CV is moving across the HRI [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced when Preemption signal is detected, while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**N/A**		Preemption was removed before the system issued a warning.
The RCVW extinguishes as preemption signal is removed [RBS-5].	**N/A**		Preemption was removed before the system issued a warning.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test.
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test.
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging		**N**	See Positional Accuracy for more information.

Test Case No. and Title			2.4.4 Type A CV Approaches with Preemption Signal Detected at Approach Entry, Preemption Signal is Removed at Midpoint, 50 mph, Dry Condition
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].			
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• The plan was to use a loop detector to deactivate train preemption. There was a hardware malfunction. Train preemption was deactivated manually. • Several Faults were raised during testing. See Issuing of System Faults.

Test Case No. and Title	**2.4.7 Type C CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 5, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no

Test Case No. and Title	**2.4.7 Type C CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This test case is similar to Test Case 2.4.2, except the vehicle type changes from A (car) to C (heavy truck) which results in a change on the deceleration rate. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status is Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is “Normal.” • This test will be performed using a Heavy Truck (type C). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box. • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case

Test Case No. and Title	**2.4.7 Type C CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results) Date: 10/30/2020

Test Case No. and Title			**2.4.7 Type C CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5] [VBS-6] [VBS-10].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8]	**Y**		

Test Case No. and Title			**2.4.7 Type C CV Approaches with Preemption Signal Detected at the Approach Midpoint, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. • Several Faults were raised during testing. See Issuing of System Faults.

Test Case No. and Title	**2.4.8 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 70 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20** **RBS-4, 5, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no

Test Case No. and Title	**2.4.8 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 70 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This test case is similar to Test Case 2.2.1h, except that the Preemption Signal detection becomes active when the CV is within the Approach Zone at a point 1/2 the distance of the Approach zone (based on initial approach entry speed), rather than at entry into the Approach Zone and the CV speed is 70 mph. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status is Active for the duration of this test. • The initial approach speed of the CV shall be 70 mph. • Pavement surface condition is dry. • The status of the RCVW system is "Normal." • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case

Test Case No. and Title	**2.4.8 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 70 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected and the variation in speed.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.4.8 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 70 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8]	**Y**		

Test Case No. and Title			**2.4.8 Type A CV Approaches with Preemption Signal Detected at the Approach Midpoint, 70 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			- The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. - Run 3 experienced the issue of an RCVW, cleared and re-issue.

Test Case No. and Title	**2.4.9 Type C CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that the System Ready graphic is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a System Available is displayed as the CV enters the approach zone and the preemption signal is not active • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is within the approach zone and approaching the HRI, there is an active Preemption signal and an RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the Approach zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that an RCVW is no longer displayed/annunciated while the CV is within the Approach zone and approaching the HRI as a result of Driver Action (CV decelerates), there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable • Analyze log files to confirm that warnings and alerts are accurate and correspond to displayed results **Secondary Objectives:** • Compare results with those of Test Case 2.2.1h to gain an understanding of the RCVW safety envelope as impacted by varying the CV distance from the HRI when the Preemption Signal is detected • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 14, 15, 16, 17, 20**

Test Case No. and Title	**2.4.9 Type C CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	RBS-4, 5, 7, 22
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV within the Approach zone and approaching the HRI, an active Preemption Signal, and a RCVW predicted for the specified conditions. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This test case is similar to Test Case 2.4.2 except that the preemption detection becomes active when the CV is within the Approach Zone at a point 3/4 the distance of the zone (based on initial approach entry speed), rather than at entry into the Approach Zone. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • HRI status is Active for the duration of this test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • The status of the RCVW system is “Normal.” • This test will be performed using a Heavy Truck (type C). The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The loop detector is positioned at the 3/4 approach point and is connected to the RIOTECH X-Spi Box.

Test Case No. and Title	**2.4.9 Type C CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	• The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets. Results will be compared with Test Case 2.2.1h to contrast the impact of the distance from HRI when Preemption Signal is detected	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.4.9 Type C CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV located beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area and the preemption signal is not active [VBS-6] [VBS-10] [RBS-5].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted. [RCVW-8] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		

Test Case No. and Title			2.4.9 Type C CV Approaches with Preemption Signal Detected at the 3/4 Approach Point, 50 mph, Dry Conditions
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		
The RCVW will extinguish after proper driver reaction and an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test.
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test.
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information.
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• The plan was to use a loop detector to activate train preemption. There was a hardware malfunction. Activation was performed manually. • Faults were not presented in any of the runs for this test.

Test Case No. and Title	**2.5.1 CV Stopped in HRI Hazard Zone**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that a System Ready is displayed when the CV is outside the Approach Zone and system functioning • Confirm that a system available is displayed when the CV is in the Approach Zone • Confirm that a Unique Warn alert to clear the HRI is displayed when the CV is stopped in the HRI regardless of the preemption status • Confirm that a System Ready is displayed when the CV leaves the HRI **Secondary Objectives:** • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is not active • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8,** **VBS-5, 6, 10, 11a, 14, 16, 20** **RBS-4, 5, 7, 22**
Brief Description	In this test case, the CV will approach the grade crossing, and then stop on the tracks (in the HRI Hazard Zone). A Unique Warn alert to clear the HRI shall be issued for the vehicle stopped in the HRI Hazard zone once the preemption is switched on. This warning is removed once the CV departs the HRI Hazard Zone. 30 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • The CV approaches the HRI and stops on the tracks in the HRI Hazard Zone. • The CV will depart the HRI after the Unique Warn alert to clear the HRI is issued. • The status of the RCVW system is “Normal.” • This test will be performed using a passenger car (type A). The following configuration states should be verified prior to test execution:

Test Case No. and Title	2.5.1 CV Stopped in HRI Hazard Zone	
Verification Phase	II – Field Test Verification	
	• Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated	
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/29/2020

			2.5.1 CV Stopped in HRI Hazard Zone
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the area beyond the HRI [VBS-16].	**Y**		
A System Available is displayed when the CV enters the approach area [VBS-6] [VBS-10].	**Y**		

Test Case No. and Title			**2.5.1 CV Stopped in HRI Hazard Zone**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Available is displayed when the CV enters and stops within the HRI Hazard Zone (prior to warning system activation).	**Y**		
A Unique Warn alert to clear the HRI displayed/annunciated while the CV is stopped in the HRI [RCVW-8] [VBS-4] [VBS-6] [VBS-10] [VBS-11a] [VBS-14] [VBS-16] [VBS-20].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
RBS will not broadcast the HRI Active message when the preemption signal is not detected [RBS-5].	**Y**		
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• 28 runs presented no errors. • 2 runs presented a location data frequency too low.

Test Case No. and Title	**2.5.2 CV Stopped, Enter / Exit the HRI with Preemption Active**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that an Approach Inform Alert is displayed when the CV is in the Approach Zone (except when RCVW alerts are issued per the note below). • Validate the accuracy of the GPS System by confirming the following: o Confirm that a System Available is displayed as soon as the CV enters the HRI (when the vehicle is moving above the configured threshold speed) o Confirm that a System Ready is displayed as soon as the CV exits the HRI • Confirm that vehicle will not receive a Unique Warn alert to clear the HRI when it is moving (above the configured threshold speed) • Confirm that if any part of the vehicle is stopped (or moving above the configured threshold speed) within the HRI Hazard Zone, the Clear HRI warning is issued **Note:** RCVW alerts and Unique Warn alert to clear the HRI may be experienced while the vehicle is moving slowly (below the configured threshold speed) between re-positioning the vehicle to progressively forward stop locations both in Approach Zone and HRI Hazard Zone, respectively. **Secondary Objectives:** • Confirm that a System Ready is displayed when the CV is outside the Approach Zone • Confirm RBS broadcasts the SPaT message at a rate of 10Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8,** **VBS-4, 5, 6, 10, 16, 24** **RBS-7, 5, 22**
Brief Description	In this test case, the CV will approach the grade crossing, and stop at various locations prior to, within, and beyond the HRI Hazard Zones (stop bars). The stop locations include: • Entire vehicle is within the Approach Zone, just outside of the HRI Hazard Zone • Front of vehicle inside the HRI Hazard Zone and rear of vehicle in the Approach Zone • Entire vehicle is beyond (outside of) the HRI Hazard Zone The CV will remain stopped for 10 minutes at each stop location to ensure appropriate alerting persists. The speed of the vehicle while re-positioning between stop locations will

<table>
<tr><td>Test Case No. and Title</td><td>2.5.2 CV Stopped, Enter / Exit the HRI with Preemption Active</td></tr>
<tr><td>Verification Phase</td><td>II – Field Test Verification</td></tr>
<tr><td></td><td>be slow both due to the short distances to traverse and to confirm alert changes between the Approach Zone, HRI Hazard Zone, and egress from the HRI Hazard Zone. Depending on the vehicle speed some warnings may or may not be issued per the note above (observing the issuance of these is not one of the primary objectives of the test, but the state changes will be recorded and detection of any issues will be undertaken in post-processing of log file data).

This test case will validate three key system characteristics:
• The accuracy of the GPS System by cross checking the locations in the log where the different DVI state changes (alerts) display relative to the actual physical location of the entrance and exit of the HRI.
• A CV will not receive a “Clear the HRI” warning as long as it is moving (above the configured speed threshold) or not within the HRI Hazard Zone.
• A CV will receive a “Clear the HRI” warning as long as any part of the vehicle is stopped within the HRI Hazard Zone.

30 minutes are allocated for conducting this test. Data will be collected during this time for later analysis.</td></tr>
<tr><td>Test Setup and Configuration</td><td>Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test:
• The CV approaches the HRI and stops at each of the locations specified above—an external observer will assist the driver
• The status of the RCVW system is “Normal.”
• This test will be performed using a passenger car (type A).

The following configuration states should be verified prior to test execution:
• Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC)
• Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast)
• CV Inspector is running
• Logging is activated</td></tr>
<tr><td>Test Procedure/Script</td><td>Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. An external observer will assist the driver in stopping at each of the</td></tr>
</table>

Test Case No. and Title	**2.5.2 CV Stopped, Enter / Exit the HRI with Preemption Active**	
Verification Phase	**II – Field Test Verification**	
	locations specified above. The CV observer will time out the duration that the vehicle should be stopped. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.5.2 CV Stopped, Enter / Exit the HRI with Preemption Active**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the area beyond the HRI [RCVW-8] [VBS-10] [VBS-16].	**N/A**	**N/A**	The test did not involve an approach to the HRI. See System Stability When Near/In/Beyond the HRI.
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before an RCVW is predicted [RCVW-8] [VBS-4] [VBS-6] [VBS-10].	**N/A**	**N/A**	The test did not involve an approach to the HRI. See System Stability When Near/In/Beyond the HRI.
Confirm that a System Available message is displayed as soon as the CV enters the HRI [RCVW-8] [VBS-16].	**N/A**	**N/A**	Test was modified from the plan to include a more thorough validation. System Stability When Near/In/Beyond the HRI.

Test Case No. and Title			2.5.2 CV Stopped, Enter / Exit the HRI with Preemption Active
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met? Y**	**N**	**Notes**
Confirm that the CV will not receive an Alert Warning it of clearing the HRI as its moving through it [RBS-5].	**Y**		Note: A Clear the HRI warning is expected to be issued when the speed is below the configured speed threshold.
Confirm that a System Ready message is displayed as soon as the CV exits the HRI [RCVW-8].	**Y**		
Confirm that the System Available message remains displayed while any portion of the vehicle occupies the HRI and the System Ready message displays only when all portions of the vehicle are clear of the HRI Approach Zone and HRI Hazard Zone [VBS-24].	**Y**		
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].	**Y**		See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			See System Stability When Near/In/Beyond the HRI.

Test Case No. and Title	**2.6.5 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Left of the Approach Zone, CV Position Re-enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that a System Ready is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert is displayed/annunciated while the CV is approaching the HRI, there is an active Preemption Signal, and a RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the approach zone, zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that the RCVW remains as the vehicle deviates to the left of the approach zone • Confirm that an RCVW is no longer displayed/annunciated when the CV is back in the Approach zone and approaching the HRI as a result of Driver Action, there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8,** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 13, 14, 15, 16, 17, 20, 26** **RBS-4, 7**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV located within the approaching zone, and it remains as the CV deviates to the left of the driving lane (simulating a GPS shift) while approaching the HRI, an active Preemption Signal, and a RCVW is predicted. The RCVW remains as the CV re-enters the driving lane and maintains its heading. Additionally, the test is to verify that the RCVW is no longer generated once the

Test Case No. and Title	**2.6.5 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Left of the Approach Zone, CV Position Re-enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	driver takes satisfactory action to permit safe stoppage prior to the HRI. This test will verify the Snap to lane function. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • The initial approach speed of the CV shall be 50 mph. • The status of the RCVW system is "Normal." • This test will be performed using a CV passenger car (type A). • CV will enter the approach and an RCVW will be issued. • CV will then deviate its location a lane over to the left of the ingress lane maintaining its heading. • CV will shift back into the ingress lane. • Driver response will be executed upon issuance of the RCVW. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case.

Test Case No. and Title	**2.6.5 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Left of the Approach Zone, CV Position Re-enters Approach Zone, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.6.5 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Left of the Approach Zone, CV Position Re-enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed while the CV is moving across the HRI [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced when Preemption signal is detected, while the CV deviates outside left the approach zone, and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is outside left the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8]	**Y**		

Test Case No. and Title			**2.6.5 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Left of the Approach Zone, CV Position Re-enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction, an Approach Inform Alert will be reissued while the CV reenters the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**N/A**	**N/A**	For safety concerns, the breaking robot was deactivated during the Position Deviation Test cases. The vehicle proceeds across the HRI for all the test runs.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See v for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• For safety concerns, the breaking robot was deactivated during the Position Deviation Test cases. The vehicle proceeds across the HRI for all the test runs.

Test Case No. and Title	**2.6.6 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Right of the Approach Zone, CV Position Enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** • Confirm that System Ready is displayed when the CV is outside the Approach Zone and system functioning • Confirm that an Approach Inform Alert displayed/annunciated while the CV is approaching the HRI, there is an active Preemption Signal, and a RCVW is not predicted • Confirm that an RCVW is displayed/annunciated while the CV is within the approach zone, zone and approaching the HRI, there is an active Preemption Signal, and a RCVW is predicted • Confirm that the RCVW remains as the vehicle deviates to the right of the approach zone • Confirm that an RCVW is no longer displayed/annunciated when the CV is back in the Approach zone and approaching the HRI as a result of Driver Action, there is an active Preemption Signal, and a RCVW is not/no longer predicted • Confirm that an Approach Inform Alert will be reissued while the CV is in the Approach Zone, preemption is active and no RCVW is not predicted • Confirm that a System Available is displayed while the CV is moving across the HRI (if applicable) • Confirm that a System Ready is displayed once the CV has departed the HRI (if applicable) **Secondary Objectives:** • Confirm RBS broadcasts the MAP message at a rate of 1 Hz • Confirm RBS broadcasts the SPaT message at a rate of 10 Hz with the appropriate approach lane status when the HRI is active
Requirements Verified	**RCVW-8,** **VBS-3b, 4, 5, 6, 7, 10, 11b, 12, 13, 14, 15, 16, 17, 20, 26** **RBS-4, 7, 22**
Brief Description	The primary purpose of this test is to verify that a RCVW is generated with the CV located within the approaching zone, and it remains as the CV deviates to the right of the driving lane (simulating a GPS shift) while approaching the HRI, an active Preemption Signal, and a RCVW is predicted. The RCVW remains as the CV re-enters the driving lane and maintains

Test Case No. and Title	**2.6.6 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Right of the Approach Zone, CV Position Enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase	**II – Field Test Verification**
	its heading. Additionally, the test is to verify that the RCVW is no longer generated once the driver takes satisfactory action to permit safe stoppage prior to the HRI. This test will verify the Snap to lane function. 3 iterations will be conducted following the same conditions described in this test case to collect multiple sets of data for later analysis.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • The initial approach speed of the CV shall be 50 mph. • The status of the RCVW system is "Normal." • This test will be performed using a CV passenger car (type A). • CV will enter the approach and an RCVW will be issued. • CV will then deviate its location a lane over to the right of the ingress lane maintaining its heading. • CV will shift back into the ingress lane. • Driver response will be executed upon issuance of the RCVW. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • Ensure the RBS is powered and operating normally (MAP and SPaT are broadcast) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case.

Test Case No. and Title	**2.6.6 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Right of the Approach Zone, CV Position Enters Approach Zone, 50 mph, Dry Conditions**	
Verification Phase	**II – Field Test Verification**	
	After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☐ Pass (met all expected results) ☒ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.6.6 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Right of the Approach Zone, CV Position Enters Approach Zone, 50 mph, Dry Conditions**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Ready is displayed while the CV is outside the approach area (this includes the CV beyond the HRI if applicable) [VBS-10] [VBS-16].	**Y**		
A System Available is displayed while the CV is moving across the HRI [VBS-10] [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced when Preemption signal is detected, while the CV deviates outside left the approach zone, and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is outside left the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8]	**Y**		

Test Case No. and Title			2.6.6 Type A CV Approaches with Preemption Signal Detected at Approach Entry, CV Position Deviates to the Right of the Approach Zone, CV Position Enters Approach Zone, 50 mph, Dry Conditions
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
[VBS-3b] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
The RCVW will extinguish after proper driver reaction, an Approach Inform Alert will be reissued while the CV reenters the Approach Zone, preemption is active and no RCVW is not predicted [VBS-12].	**N/A**	**N/A**	For safety concerns, the breaking robot was deactivated during the Position Deviation Test cases. The vehicle proceeds across the HRI for all the test runs.
RBS broadcasts the HRI Configuration Data Format (HCDF) once per second [RBS-7].	**Y**		See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI configuration data during field test
RBS broadcasts the HRI Active message 10 times per second [RBS-4].		**N**	See DSRC Messaging and Data Processing Latency Requirement Verification for more information on the broadcast rate of the HRI Active message during field test
The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters [VBS-5].		**N**	See Positional Accuracy for more information
The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol [RBS-22].	**Y**		
Notes			• Several Faults were raised during testing. See Issuing of System Faults. • Log files show the vehicle was not in lane, see Lane Shift.

Test Case No. and Title	**2.7.1a Loss of DSRC after CV has Received an RCVW**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** To demonstrate system's capability to detection and response to a loss of communications due to a failure with the DSRC radio.
Requirements Verified	**RCVW-8,** **VBS-1, 3a, 3b, 3c, 4, 6, 7, 10,11b,11c, 12, 13, 14, 15, 17,18,19, 20** **RBS-10,16**
Brief Description	The purpose of this test is to demonstrate how the RCVW system will behave when there is a loss of DSRC after the system has issued an RCVW. As the CV enter the approach zone, with an active preemption signal, an approach inform will be displayed/annunciated. An RCVW will then be displayed/annunciated. As the driver begins to respond, there is a loss of DSRC signal. The system will generate a graphic and audio message informing the driver of a System Fault.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • Train preemption signal detected at/prior to CV Approach Zone entry. • The initial approach speed of the CV shall be 50 mph. • The status of the RCVW system is "Normal." • This test will be performed using a CV passenger car (type A). • Driver response will be executed upon issuance of the RCVW, but prior to driver action resolving the RCVW DSRC communications are lost. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed:

Test Case No. and Title	**2.7.1a Loss of DSRC after CV has Received an RCVW**	
Verification Phase	**II – Field Test Verification**	
	• The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.7.1a Loss of DSCRC after CV has Received an RCVW**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Available is displayed while the CV is outside the approach area [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-1] [VBS-3a][VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-1] [VBS-3a] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-11c] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		

Test Case No. and Title			**2.7.1a Loss of DSCRC after CV has Received an RCVW**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Fault alert is displayed/announced on the DVI as the DSRC signal is detected to be lost [VBS-18] [VBS-19].	**Y**		A SPaT Data not received error was raised as a result of the loss of DSRC.
Verify in the logs that that System Fault was generated due to a loss of DSRC communication [RBS-10] [RBS-16].	**Y**		Verified.
Notes			The DVI displayed the System Fault message as expected

Test Case No. and Title	**2.7.1b Loss of DSRC Prior to Entering the MAP**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** To demonstrate system's capability to detection and response to a loss of communications due to a failure with the DSRC radio.
Requirements Verified	**RCVW-8,** **VBS-16,18,19** **RBS-10,16**
Brief Description	The purpose of this test is to demonstrate how the RCVW system will behave when there is a loss of DSRC prior to the CV entering the approach zone. The system will generate a graphic and audio message informing the driver of a System Fault when it detects that it was expecting to receive a DSRC signal from a known HRI as it is approaching to it but failed to do so.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • The DSRC radio will be disabled prior to the start of the test. • The initial approach speed of the CV shall be 50 mph. • Pavement surface condition is dry. • This test will be performed using a passenger car (type A). • No driver response, the vehicle advances through the HRI. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power and GPS) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.

Test Case No. and Title	**2.7.1b Loss of DSRC Prior to Entering the MAP**
Verification Phase	**II – Field Test Verification**
	• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results) — Date: 10/30/2020

Test Case No. and Title			**2.7.1b Loss of DSRC Prior to Entering the MAP**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Available is displayed while the CV is outside the approach [RCVW-8] [VBS-16].	**Y**		
A System Fault alert is displayed/announced on the DVI as the VBS detects the absence of an expected DSRC signal [VBS-18] [VBS-19].	**Y**		A SPaT Data not received error was raised as a result of the loss of DSRC.
Verify in the logs that that System Fault was generated due to a loss of DSRC communication [RBS-10] [RBS-16].	**Y**		
Notes			The DVI displayed the System Fault message as expected.

Test Case No. and Title	**2.7.2 Loss of RTK Fix (GPS)**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** The purpose of this test is to demonstrate how the RCVW system will behave when there is a loss of RTK Fix from the GNSS communication on approach with the Preemption Signal active.
Requirements Verified	**RCVW-8,** **VBS-1, 3a, 3b, 3c, 4, 6, 7, 10, 11b,11c, 12, 13, 14, 15, 16, 17,18,19, 20** **RBS-10,16**
Brief Description	As the CV enter the approach zone, with an active preemption signal, an approach inform will be displayed/annunciated. An RCVW will then be displayed/annunciated. As the driver begins to respond, there is a loss of RTK Fix in the VBS. The system will generate a graphic and audio message informing the driver of a System fault.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • Train preemption signal detected at/prior to CV Approach Zone entry. • The initial approach speed of the CV shall be 50 mph. • The status of the RCVW system is “Normal.” • This test will be performed using a CV passenger car (type A). • Driver response will be executed upon issuance of the RCVW, but prior to driver action resolving the RCVW, GPS signal is lost. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.

Test Case No. and Title	**2.7.2 Loss of RTK Fix (GPS)**	
Verification Phase	**II – Field Test Verification**	
	• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.7.2 Loss of RTK Fix (GPS)**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Available is displayed while the CV is outside the approach area (this includes entering and moving through the HRI if applicable) [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-1] [VBS-3a][VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-1] [VBS-3a] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-11c] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**Y**		

Test Case No. and Title			2.7.2 Loss of RTK Fix (GPS)
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Fault alert is displayed/announced on the DVI as the GPS signal is detected to be lost [VBS-18] [VBS-19].	**Y**		An RTK Data not Received Error was raised as a result of the loss of DSRC.
Verify in the logs that that System Fault was generated due to a loss of GPS signal [RBS -10] [RBS-16].	**Y**		
Notes			The DVI displayed the System Fault message as expected.

Test Case No. and Title	**2.7.5 Loss of MAP**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** The purpose of this test is to demonstrate how the RCVW system will behave when there is a loss of MAP on approach with the Preemption Signal active.
Requirements Verified	**RCVW-8,** **VBS-1, 3a, 3b, 3c, 4, 6, 7, 10, 11b,11c, 12, 13, 14, 15, 17,18,19, 20** **RBS-4,7,10,16**
Brief Description	The purpose of this test is to demonstrate how the RCVW system will behave when there is a loss of MAP on approach with the Preemption Signal active. As the CV enter the approach zone, with an active preemption signal, an approach inform will be displayed/annunciated. An RCVW will then be displayed/annunciated. As the driver begins to respond, there is a loss of MAP from the RBS. The system will generate a graphic and audio message informing the driver of a System Fault.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • Train preemption signal detected at/prior to CV Approach Zone entry. • The initial approach speed of the CV shall be 50 mph. • The status of the RCVW system is “Normal.” • This test will be performed using a CV passenger car (type A). • Driver response will be executed upon issuance of the RCVW, but prior to driver action resolving the RCVW, MAP data is loss. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed:

Test Case No. and Title	**2.7.5 Loss of MAP**	
Verification Phase	**II – Field Test Verification**	
	• The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case. • The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case. After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.7.5 Loss of MAP**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Available is displayed while the CV is outside the approach area (this includes entering and moving through the HRI if applicable) [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-1] [VBS-3a][VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-1] [VBS-3a] [VBS-3b] [VBS-3c] [VBS-4] [VBS-	**Y**		

Test Case No. and Title			**2.7.5 Loss of MAP**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
6] [VBS-7] [VBS-10] [VBS-11b] [VBS-11c] [VBS-14] [VBS-15] [VBS-17] [VBS-20].			
A System Fault alert is displayed/announced on the DVI as the loss of MAP occurs. [VBS-18] [VBS-19] [RBS-10].	**Y**		A MAP Data not received error was raised as a result of the loss of DSRC.
Verify in the logs that that System Fault was generated due to a loss of MAP [RBS-16] [RBS-10].	**Y**		
Notes			A restart of the Location plugin was executed prior to the start of this test. See section Processor Lag. The DVI displayed the System Fault message as expected.

Test Case No. and Title	**2.7.6 Loss of IEEE 1570 Heartbeat**
Verification Phase	**II – Field Test Verification**
Test Objectives	**Primary Objectives:** The purpose of this test is to demonstrate how the RCVW system will behave when there is a loss of IEEE 1570 Heartbeat Signal on approach with the Preemption Signal active.
Requirements Verified	**RCVW-8,** **VBS-1, 3a, 3b, 3c, 4, 6, 7, 10, 11b,11c, 12, 13, 14, 15, 16, 17,18,19, 20** **RBS-10,16**
Brief Description	As the CV enter the approach zone, with an active preemption signal, an approach inform will be displayed/annunciated. An RCVW will then be displayed/annunciated. As the driver begins to respond, there is a loss of I2.4.21570 signal. The system will generate a graphic and audio message informing the driver of a Heartbeat fault.
Test Setup and Configuration	Prior to beginning the test, the Test Administrator shall verify that the following conditions are planned for this test: • Train preemption signal detected at/prior to CV Approach Zone entry. • The initial approach speed of the CV shall be 50 mph. • The status of the RCVW system is "Normal." • This test will be performed using a CV passenger car (type A). • Driver response will be executed upon issuance of the RCVW, but prior to driver action resolving the RCVW, IEEE Heartbeat signal is lost. The following configuration states should be verified prior to test execution: • Ensure the VBS, including the DVI, are powered and operating normally (Power, GPS, and DSRC) • CV Inspector is running • Logging is activated
Test Procedure/Script	Prior to beginning the test, the personnel will be located at their assigned position(s) per Table 5 above. After the test the following shall be performed: • The administrator and algorithm observer shall ensure the system did not enter an error state, system is active and ready for the next test case.

Test Case No. and Title	**2.7.6 Loss of IEEE 1570 Heartbeat**	
Verification Phase	**II – Field Test Verification**	
	• The administrator shall confirm that data was properly recorded by all test personnel and indicate to proceed to next iteration/test case After the test, the administrator and algorithm observer shall access and review logged files to confirm they are accurate and correspond to observed results as recorded on data sheets.	
Pass / Fail	☒ Pass (met all expected results) ☐ Fail (did not meet one or more expected results)	Date: 10/30/2020

Test Case No. and Title			**2.7.6 Loss of IEEE 1570 Heartbeat**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Available is displayed while the CV is outside the approach area (this includes entering and moving through the HRI if applicable) [VBS-16].	**Y**		
An Approach Inform Alert is displayed/announced while the CV is within the approach zone and approaching the HRI with an active Preemption Signal before driver action is taken. [RCVW-8] [VBS-1] [VBS-3a][VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-12] [VBS-13] [VBS-14] [VBS-17].	**Y**		
An RCVW is displayed/annunciated while the CV is within the approach zone and approaching the HRI with an active Preemption Signal throughout the approach before driver action is taken [RCVW-8] [VBS-1] [VBS-3a] [VBS-3b] [VBS-3c] [VBS-4] [VBS-6] [VBS-7] [VBS-10] [VBS-11b] [VBS-11c] [VBS-14] [VBS-15] [VBS-17] [VBS-20].	**N/A**		The error was raised prior to the issue of an RCVW.

Test Case No. and Title			**2.7.6 Loss of IEEE 1570 Heartbeat**
Verification Phase			**II – Field Test**
Expected Results [requirement]	**Met?**		**Notes**
	Y	**N**	
A System Fault alert is displayed/announced on the DVI as the loss of IEEE 1570 Heartbeat signal occurs. [VBS-18] [VBS-19] [RBS-16].	**Y**		A SPaT Data not available was raised as a result of removing the IEEE heartbeat.
Verify in the logs that that System Fault was generated due to a loss of IEEE 1570 Heartbeat [RBS-10] [RBS-16].	**Y**		
Notes			The DVI displayed the System Fault message as expected.

Appendix. RCVW Requirements Traceability Matrix

Table 10 identifies the FT&E test case(s) in which each requirement from the RCVW System Requirements Specification document [2] is verified. Scenario-based tests for FT&E are a subset of those conducted in BT&E, but revised to reflect how field testing is conducted. As such, these test cases use the same numbering as that used in BT&E, with the exception that select test cases are broken out instead of written as a single test case like in the BT&E plan (i.e., 2.2.1e, 2.4.2h, and 2.4.2l). Several test cases are conducted in FT&E but not in BT&E such as tests involving road conditions (i.e., 2.2.7, 2.2.8, 2.2.9 and 2.2.10) and several test exploring the results when varying the vehicle type. The corresponding BT&E test case numbers for scenario-based requirements for FT&E that were previously tested in discrete or scenario-based tests in BT&E are not reflected in this table. However, since all requirements for RCVW are listed, references are made to BT&E test case numbers when only a BT&E test will be used to verify the requirement.

Table 10. Identifies the FT&E Test Case(s) Where Each RCVW System Requirement Specification is Verified

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases	Met?
			Scenario-Based	
RCVW-1	RCVW System	The system shall include a vehicle-based subsystem component and a roadside-based subsystem component.	Evaluated in BT&E 1.1.1, 1.1.6, 1.1.7	YES
RCVW-3	RCVW System	The system shall be modular and sufficiently extensible to address all design objectives defined in this SRS.	Evaluated in BT&E 1.1.1	YES
RCVW-5	RCVW System	The only point(s) of connection between the RCVW system and the train detection system shall be the preemption signal available through a track-circuit or IEEE 1570-compliant serial interface.	Evaluated in BT&E 1.1.1, 1.1.6, 1.1.7	YES
RCVW-7	RCVW System	The vehicle-based subsystem OBU and roadside-based subsystem RSU shall communicate in compliance with SAE J2735-2016, IEEE 1609, SAE J2739, and SAE J2450 (ITIS) Standards.	Evaluated in BT&E 1.1.2	YES
RCVW-8	RCVW System	All "over-the-road" licensed vehicles (i.e., vehicles of all vehicle classes) are included.	2.1.1, 2.2.1e, 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, , 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
RCVW-11	RCVW System	The system shall be compliant with CV Personally Identifiable Information (PII) standards and guidelines	Evaluated in BT&E 1.1.4	YES

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases	Met?
			Scenario-Based	
VBS-1	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem DVI shall have the capability to produce alerts suitable for all licensed drivers.	2.3.1, 2.7.1a, 2.7.2, 2.7.5, 2.7.6	YES
VBS-2	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem DVI shall have a human-machine interface (HMI) that is configurable to be audible, visual, both, or neither by the driver	Evaluated in BT&E 1.1.3	YES
VBS-3a	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem will present alerts that conform to In-Vehicle Display Icons and Other Information Elements, Volume 1: Guidelines and Human Factors Design Guidance for Driver-Vehicle Interfaces.	Evaluated in BT&E 1.1.3	YES
VBS-3b	Vehicle-Based Subsystem (VBS)	The system shall provide two-stage alert messaging consisting of an informational, and, if applicable, a warning alert. *Note: An Approach Inform Alert is non-obtrusive and serves to inform the driver of an active HRI ahead. This alert primes the vehicle operator for the potential need to stop at the HRI. A warn alert is obtrusive and occurs if it is predicted that the vehicle will not stop prior to the HRI using non-emergency braking. This alert serves to notify the vehicle operator that remains unaware of the active HRI ahead or who has decided to exercise poor judgement.*	2.2.1h, 2.2.1e, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4 2.4.7, 2.4.8, 2.4.9, 2.6.5, 2.6.6, 2.7.1a, 2.7.2, 2.7.5, 2.7.6	YES
VBS-3C	Vehicle-Based Subsystem (VBS)	The inform and warn alerts shall be multimodal in nature. *Note: Multimodal alerts may be visual, auditory or haptic.*	Evaluated in BT&E 1.1.3	YES
VBS-4	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall produce alerts that can be implemented in all vehicle classes and types equipped with appropriate connected vehicle technologies. *Note: vehicle-specific installation procedures may be required.*	2.2.1h, 2.2.1e, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.2, 2.7.5, 2.7.6	YES
VBS-5	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall receive and process RTK corrections using the RTCM messaging protocol broadcasted from the roadside-based subsystem to achieve a R95 probability of horizontal position accuracy of less than or equal to 1.5 meters.	2.1.1, 2.2.1e 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6	Partially met (see Positional Accuracy)
VBS-6	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall process HRI configuration (GID) data that describes the geographic composition of the intersection	2.1.1, 2.2.1e 2.2.1h, 2.2.1l, 2.2.3, , 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.2, 2.7.5, 2.7.6	YES
VBS-7	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall be able to provide direction specific alerts.	2.2.1h, 2.2.1e, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a,	YES

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases	Met?
			Scenario-Based	
		Note: For clarity, the application shall be able to provide alerts to vehicles approaching the HRI and not alert vehicles departing the HRI.	2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.6.5, 2.6.6, 2.7.1a, 2.7.2, 2.7.5, 2.7.6	
VBS-8	Vehicle-Based Subsystem (VBS)	The system shall provide a driver-vehicle interface (DVI) and, alternately, support display to OEM displays through standardized physical and electrical outputs.	Evaluated in BT&E 1.1.1	YES
VBS-9a	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall not interfere with any of the onboard safety systems, especially automotive industry automated safety systems.	Evaluated in BT&E 1.1.7	YES
VBS-9b	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall not interfere with any existing infrastructure subsystems (traffic control and HRI warning systems).	Evaluated in BT&E 1.1.6	YES
VBS-10	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall determine if the vehicle is within the HRI Hazard Zone and/or the HRI Approach Zone.	2.1.1, 2.2.1e, 2.2.1l, 2.2.1h, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.2, 2.7.5, 2.7.6	YES
VBS-11a	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall issue a unique warn alert that directs users to take evasive action to clear the HRI by any means when the vehicle is stopped within the HRI Hazard Zone. *Note: In the future, when SAE J2735 has been modified to better support rail applications and the intersection zone (HRI Hazard Zone) or when an alternative approach is found to be viable, it is anticipated that the RCVW tool will be capable of distinguishing whether the crossing is active when the vehicle is within the HRI Hazard Zone. At that time, it is desired that this requirement will be transformed into two requirements – one for when the crossing is active where a warn alert such as the one described here is issued, and one when the crossing is not active where a new Approach Inform Alert will instead be presented.*	2.5.1	YES
VBS-11b	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall issue warnings while the HRI is active when the vehicle is in the HRI Approach Zone if the vehicle is not decelerating sufficiently to stop safely before the HRI using non-emergency braking.	2.2.1h, 2.2.1e, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.4.2, 2.4.7, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.3a, 2.4.3b, 2.4.4, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
VBS-11c	Vehicle-Based Subsystem (VBS)	The warning alert shall use a dynamic visual icon(s) and invasive auditory alert(s) in accordance with Campbell et al. (2016). Human Factors Design Guidance for Driver-Vehicle Interfaces.	Evaluated in BT&E 1.1.3	YES
VBS-12	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall issue an Approach Inform Alert to the vehicle operator when the crossing ahead is active	2.2.1h, 2.2.1e, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, , 2.3.1, 2.4.1, 2.4.2, 2.4.3a,	YES

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases	
			Scenario-Based	
		and rail crossing signage for an active crossing is within visual range according to the Guidelines for Advance Placement of Warning Signs in Table 2C-4 of the 2009 Manual on Uniform Traffic Control Devices (MUTCD), Revision 2, June 13, 2012. *Note: These guidelines identify where to place a warning sign (i.e. stop sign) in advance of a location with a potential stop condition according to the speed of the vehicle. The presentation of an Approach Inform Alert is limited to approaches toward active rail grade crossings to avoid nuisance alerting.*	2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	
VBS-13	Vehicle-Based Subsystem (VBS)	The Approach Inform Alert shall use static visual icons and non-invasive audible alert(s) in accordance with Campbell et al. (2016). Human Factors Design Guidance for Driver-Vehicle Interfaces.	Evaluated in BT&E 1.1.3	
VBS-14	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall process the HRI Active message in the context of its position with respect to the HRI, its instantaneous speed, acceleration, and other vehicle parameters to determine if an RCVW should be issued.	2.2.1h, 2.2.1e, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, , 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2. 2.7.5, 2.7.6	YES
VBS-15	Vehicle-Based Subsystem (VBS)	An RCVW warning shall be presented to the vehicle operator based on: 85th percentile driver response time, vehicle characteristics (i.e., vehicle class), and vehicle telematics (i.e. velocity, acceleration).	2.2.1e, 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	
VBS-16	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall not provide warnings when it is not inside the HRI Hazard Zone or HRI Approach Zone.	2.2.1e, 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
VBS-17	Vehicle-Based Subsystem (VBS)	Once issued, the graphical component of an Approach Inform Alert will persist while the vehicle is within the approach zone, except when superseded by a warning or fault alert, or when the crossing becomes inactive.	2.2.1e, 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	
VBS-18	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall issue a fault alert to the vehicle operator when the RCVW system is not functioning in "normal" operations mode. A fault alert will be triggered when the VBS does not receive critical information, including: 1) Position information a) GNSS information being received at a rate lower than 10 Hz	2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases Scenario-Based	Met?
		b) GNSS solution not reaching and RTK fix, either floating or fixed integer 2) MAP 3) SPaT (which includes loss of the IEEE 1570 interface communication heartbeat from the HRI warning system, when this interface is used) 4) DSRC communications (MAP and SPaT) when expected and needed		
VBS-19	Vehicle-Based Subsystem (VBS)	Fault alerts shall supersede all other annunciations.	2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
VBS-20	Vehicle-Based Subsystem (VBS)	Warn alerts shall supersede Approach Inform Alerts.	2.2.1e, 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6, 2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
VBS-22	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall be capable of receiving messages sent by the roadside-based subsystem within 50 ms.	2.1.1, 2.2.1e, 2.2.1h, 2.2.1l, 2.2.7, 2.2.9	YES
VBS-23	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall be capable of processing received data within 85 ms.	2.1.1, 2.2.1e, 2.2.1h, 2.2.1l, 2.2.7, 2.2.9	YES
VBS-24	Vehicle-Based Subsystem (VBS)	The vehicle-based subsystem shall know the position of the GNSS antenna relative to the front of the vehicle and the rear of the vehicle.	2.5.2	YES
RBS-1	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall interoperate with current infrastructure safety systems (e.g. traffic control and Train Approaching warning devices) in accordance with NEMA TS 2-2016 v03.07.	Evaluated in BT&E 1.1.2	YES
RBS-2	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall operate using 60 Hz 115VAC power as the primary power source.	Evaluated in BT&E 1.1.1	YES
RBS-2B	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall determine HRI crossing status using preemption signal information from a IEEE 1570-compliant serial interface or from a voltage-based interconnection circuit.	Evaluated in BT&E 2.4.4	YES
RBS-3	Roadside-Based Subsystem (RBS)	The infrastructure-based communication equipment shall be compliant with the V2I Hub Reference Implementation platform.	Evaluated in BT&E 1.1.1	YES
RBS-4	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall broadcast the HRI Active message 10 times per second when an associated HRI controller activates a preemption signal.	2.2.1e, 2.2.1l, 2.2.1h, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, , 2.3.1, 2.4.1, 2.4.2, 2.4.3a,	NO. See DSRC Messaging and Data

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases	Met?
			Scenario-Based	
			2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2 2.6.5, 2.6.6	Processing Latency Requirement Verification
RBS-5	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall stop broadcasting the HRI Active message when the HRI controller deactivates the preemption signal(s).	2.1.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2	YES
RBS-7	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall broadcast the HRI Configuration Data Format (HCDF) once per second.	2.1.1, 2.2.1e, 2.2.1l 2.2.1h, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2 2.6.5, 2.6.6	YES
RBS-10	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall execute periodic BIST, which includes a default mode that, if possible, depending on the nature of the failure, informs the driver via the vehicle-based subsystem when critical components are offline.	2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
RBS-11	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall employ methods to prevent unauthorized physical and cyber access.	Evaluated in BT&E 1.1.5	YES
RBS-12	Roadside-Based Subsystem (RBS)	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 DOT for V2I communications will be exercised.	Evaluated in BT&E 1.1.2 (other than security aspects); SCMS is not being implemented	YES
RBS-13	Roadside-Based Subsystem (RBS)	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/A - SCMS is not being implemented	N/A
RBS-16	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall identify and log system failures to the extent that it is practicable.	2.7.1a, 2.7.1b, 2.7.2, 2.7.5, 2.7.6	YES
RBS-18	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall incorporate self-recovering routines to recover from a major system failure associated with firmware/software systems.	Evaluated in BT&E 1.1.8	YES
RBS-20	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall not interfere with any HRI infrastructure subsystems.	Evaluated in BT&E 1.1.6	YES
RBS-21	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall be capable of receiving HRI message packets across the IEEE 1570 serial interface in less than 250 ms conforming to the IEEE1570 standard.	2.1.1, 2.2.1e, 2.2.1h, 2.2.1l, 2.2.7, 2.2.9	YES. See Verification of Requirement RBS-21

RCVW Rqmt No.	System/Subsystem	Requirement	Phase II RCVW FT&E Test Cases	Met?
			Scenario-Based	
RBS-22	Roadside-Based Subsystem (RBS)	The roadside-based subsystem shall be capable of generate and broadcast RTK corrections using the RTCM messaging protocol.	2.1.1, 2.2.1e 2.2.1h, 2.2.1l, 2.2.3, 2.2.5, 2.2.6, 2.2.7, 2.2.8, 2.2.9, 2.2.10, 2.3.1, 2.4.1, 2.4.2, 2.4.3a, 2.4.3b, 2.4.4, 2.4.7, 2.4.8, 2.4.9, 2.5.1, 2.5.2, 2.6.5, 2.6.6	YES

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
AASHTO	American Association of State Highway and Transportation
ABS	Anti-Locking Brake System
BT&E	Bench Test and Evaluation
BTR	Breaking and Throttle Robot
CPU	Central Processing Unit
CEP	Circular Error Probable
CP	Computing Platform
ConOps	Concept of Operations
CV	Connected Vehicle
CAN	Controller Area Network
DAQ	Data Acquisition System
DSRC	Dedicated Short-Range Communication
DIO	Digital Input/Output
DVI	Driver-Vehicle Interface
FMVSS	Federal Motor Vehicle Safety Standards
FT&E	Field Test & Evaluation
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
HCDF	HRI Configuration Data File
HRIC	HRI Controller
HRI	Highway-Rail Intersection
HRA	Honda Research & Development Americas
HDOP	Horizontal Dilution of Precision
HID	Human Interface Device
ITS-JPO	Intelligent Transportations System Joint Program Office
JSON	JavaScript Object Notation
MUTCD	Manual on Uniform Traffic Control Devices
MAP	MAP Data, Roadway Geometry and Attribute Data (aka GID)
OBD	On-Board Diagnostics

ACRONYMS	EXPLANATION
OBU	On-Board Unit (DSRC radio in VBS)
OEM	Original Equipment Manufacturer
PCAP	Paquet Capture
POE	Power Over Ethernet
RTCM	Radio Technical Commission for Maritime Services
RCVW	Rail Crossing Violation Warning
RGB	Red Green Blue
RTK	Real-Time Kinematic
RIOTECH	Rio Grande Pacific Technology
RBS	Roadside-Based Subsystem (an RCVW subsystem)
RSU	Roadside Unit (DSRC radio in RBS)
SPaT	Signal Phase and Timing
TMX	Transportation Message Exchange
TRC	Transportation Research Center
UTC	Universal Time Coordinated
VBS	Vehicle-Based Subsystem (an RCVW subsystem)
V2I	Vehicle-to-Infrastructure