Rail-Crossing Violation Warning (RCVW) Standard Operating Procedures – SPAT, MAP and RTCM Messaging - Final

Prepared by:

Battelle
505 King Avenue
Columbus, Ohio 43201

Submitted to:

Federal Railroad Administration
1200 New Jersey Avenue, S.E.
Washington, D.C. 20590

March 25, 2021

Produced by The U.S. Department of Transportation

with

Support from Battelle under Contract 693JJ618C000019

Federal Railroad Administration
John A. Volpe National Transportation Systems Center

Notice

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

1. REPORT DATE	**2. REPORT TYPE**	**3. DATES COVERED**
03-25-2021	Standard Operating Procedure	

4. TITLE AND SUBTITLE Rail Crossing Violation Warning (RCVW) Standard Operating Procedures – SPAT, MAP and RTCM Messaging	**5a. CONTRACT NUMBER** 693JJ6-18-C-000019
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Gregory M. Baumgardner	**5d. PROJECT NUMBER**
	5e. TASK NUMBER Task 4
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Battelle 505 King Avenue Columbus, Ohio 43201	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Office of Research, Development and Technology Washington, DC 20590	**10. SPONSOR/MONITOR'S ACRONYM(S)** FRA **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTES

14. ABSTRACT (Maximum 200 words)

This document details the procedures needed to operate the RCVW connected vehicle (CV) prototype application. Specifically, this document offers instructions and assistance for creating an appropriate map for the highway-rail intersection (HRI), setting up connectivity to the HRI preemption signal, and broadcasting real-time kinematic (RTK) position corrections from the roadside to the vehicle. The standard operating procedures laid out in this document are crucial to the proper functionality since the RCVW application requires precise signaling and positioning

15. SUBJECT TERMS

Rail Crossing Violation Warning, V2I, Standard Operating Procedure, Connected Vehicles, Safety Application, MAP, SPAT

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**		31	**19b. TELEPHONE NUMBER** *(Include area code)*

Table of Contents

List of Figures

1 Introduction

1.1 Overview

The Rail-Crossing Violation Warning (RCVW) application is comprised of connected-vehicle (CV) software that transmits the pre-emption signal state from Highway-Rail Intersection (HRI) equipment from the roadside unit (RSU) radio to the on-board unit (OBU) radio. The messages that are broadcast are to be used within the application software to determine the current state of the HRI signal, and to enhance the accuracy of the current distance of the vehicle to the HRI. At a minimum, three messages defined in the Society of Automotive Engineers (SAE) International J2735 message set must be transmitted across the Dedicated Short-Range Communication (DSRC) safety channel:

- The MapData message (MAP) for the static position and geometry of the HRI.
- The Signal, Phase and Timing (SPaT) message for the dynamic HRI signal state.
- The Radio Technical Commission for Maritime Services (RTCM) correction message for real-time Differential Global Navigation Satellite System (DGNSS) position augmentation.

MAP, SPaT and RTCM messages are modeled using the Abstract Syntax Notation One (ASN.1), which may be encoded in several different forms, including human-readable Extensible Markup Language (XML). Unfortunately, while the SAE standard details the makeup of each message, there is scarce instruction on the information required to fill the structure. Moreover, the original use case for these messages is meant for a typical urban traffic light controlled intersection, and specific guidelines on use for railways have thus far been absent. Finally, the setup and configuration of RCVW hardware and software components might affect how these messages are processed.

This document covers the standard operating procedures for the infrastructure signaling adopted by RCVW. Procedures are created for each of the three J2735 messages, including the contents of the message, how it is created, and how to configure the RCVW application on the roadside-based subsystem (RBS) for broadcast, and if necessary, associated changes required on the vehicle-based subsystem (VBS). Some general concepts may apply across others CV applications, but the primary focus is the HRI application.

1.2 Architecture

The RCVW application software utilizes the existing United States Department of Transportation (US DOT) Vehicle to Infrastructure (V2I) Reference Implementation framework, informally known as V2I Hub, or more recently Vehicle to Everything (V2X) Hub. This framework provides the toolset to develop CV applications through a plugin architecture built on top of a simplified message broker design. The V2X Hub software functions both in-vehicle and at the roadside to facilitate the communications between them. The various plugins, many of which have been built across numerous US DOT CV initiative projects, communicate with a rapid JavaScript Object Notation (JSON)-based message exchange, often culminating in an automated response to some safety concern.

The general architecture for the RCVW application within the broader V2X Hub suite is detailed in Figure 1. The roadside functionality and associated impact on the RCVW Plugin in-vehicle are the primary concerns for this document. While multiple physical hardware components facilitate the interfaces described in this architecture (see Architecture and Design document [FHWA-JPO-16-410]), each of the software components in the figure reside exclusively on the RBS or VBS computing platform. This document assumes the hardware is setup properly and focuses only on the additional software configurations needed for proper signaling operation. See installation document for hardware and software setup [RCVW Standard Operating Procedure - Hardware and Software Configuration (Baumgardner, Paselsky, & Sanchez-Badillo, 2021)]. Some of the V2X Hub standard plugin configurations, such as for the DSRC immediate forward plugin, are further discussed within the V2I Software Configuration Guide[1] [FHWA-JPO-645].

The MAP plugin is programmed to repeatedly broadcast the static HRI MAP developed with the aid of the US DOT Intersection Situation Data (ISD) Builder Tool (ISD Builder Tool for J2735 3/2016, n.d.). An associated SPaT message indicating the current HRI signal state is generated by the HRI Status Plugin. The RTCM Plugin can connect to a Networked Transport of RTCM via Internet Protocol (NTRIP) caster or better directly to a base station Global Navigation Satellite System (GNSS) receiver to generate a set of RTCM correction messages. All messages are routed through the V2X Hub Core and picked up by the DSRC Message Manager Plugin for DSRC transmission using the User Datagram Protocol (UDP)-based immediate forward capability built into the RSU 4.1 specification. The on-board Message Receiver Plugin injects these same messages off the incoming radio into the V2X Hub running inside the vehicle so that they may be distributed to the other various plugins performing the RCVW safety operations.

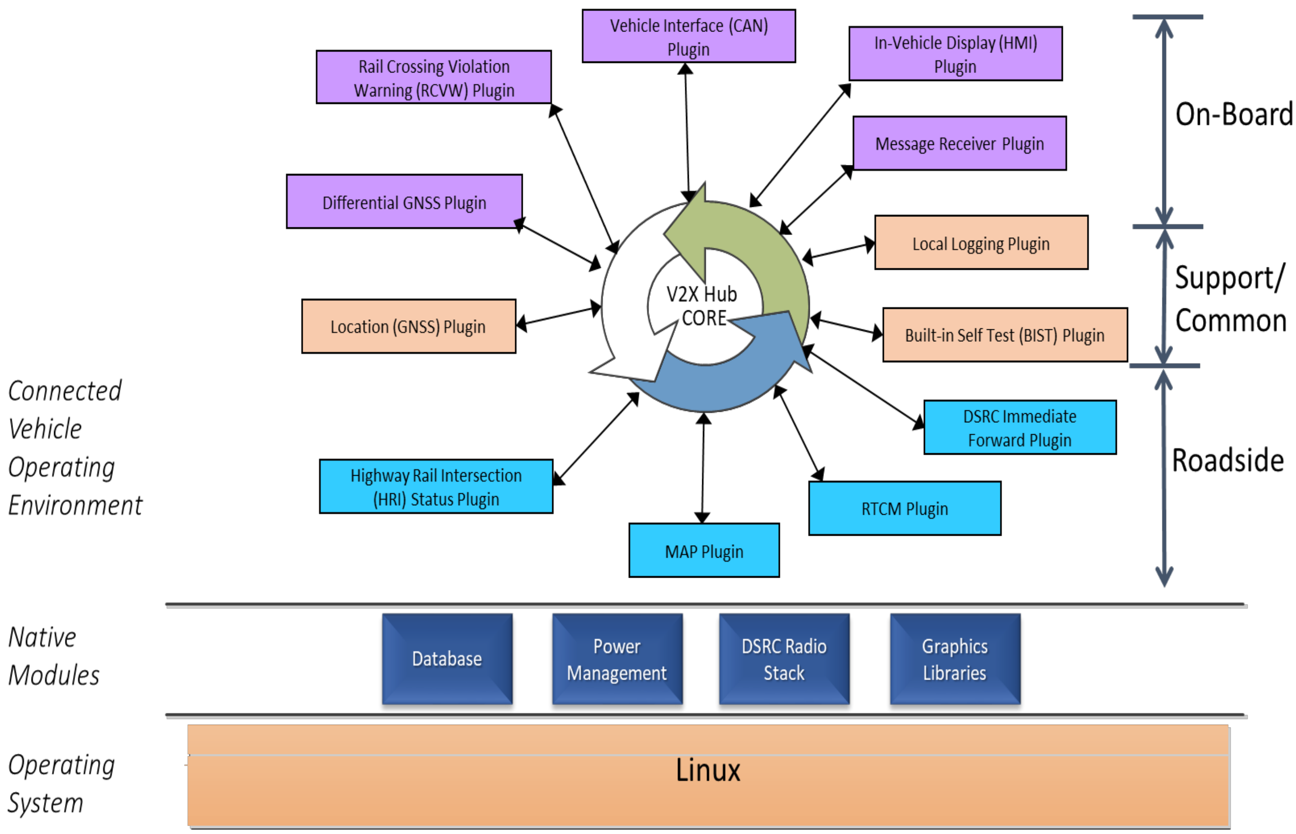

Figure 1. RCVW Architecture Within the Overall V2X Hub Reference Framework

---

[1] https://github.com/OSADP/V2I-Hub/tree/master/Support%20Documents

2 Standard Operating Procedure for MAP

A SAE J2735 MapData message provides the appropriate method for constructing and distributing the intersection geometry to the vehicle but consigns most implementation details to the programmer of the RCVW application. For RCVW to function properly, lanes are created within this MAP that represent vehicle entry lanes approaching the HRI, as well as exit lanes leaving the HRI. Additionally, a separate lane or set of lanes are required to represent the railway track itself. The vehicle and rail lanes, however, must be in separate signal groups since the accompanying SPaT messages will signal a stop (red-light) condition for the vehicle approach lane while a train is present and a proceed (green-light) condition when there is no train present. This section describes the procedure for building the geometric representation of the HRI and communicating it over the DSRC safety channel. This requires the Map Plugin and DSRC Immediate Forward Plugin (see Figure 1) on the RBS, as well as an external MAP creator tool such as the ISD Builder.

Message Contents

The key for proper RCVW operation is to build the geometry of the HRI such that alerts occur at recommended distances. RCVW alerting occurs in two phases. The Inform alert is issued at any point in which the vehicle is in an approach lane and a train is present. A second, more intrusive, Warn alert occurs at any point within the approach lane at which the Decision Sight Distance as defined by the American Association of State Highway Officials (AASHTO) Green Book (AASHTO, 2018) at the approaching vehicle speed exceeds the total distance from the stop bar at the end of the lane. Therefore, by design, the optimal length of a vehicle approach lane in the MAP should be representative of that Decision Sight Distance from the traditional Warning Sign Placement for the highway-rail grade crossing signage as defined in the Manual on Uniformed Traffic Control Devices (MUTCD) (Federal Highway Administration, 2009) for the posted speed limit or 85th percentile (typical) speed on the highway. 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 (MUTCD Table 2C-4 Condition A in this example), an approach lane for the vehicle should begin at 535 + 990 = 1525 feet from the stop bar. This ensures that if a train is present, an inform shall occur upon entering the MAP approach lane, and the warn may occur at least as far away as where the fixed sign placement would have been. Note, however, that unlike the traditional signage, the active RCVW warn alert may also occur (or re-occur) at any position following, up to the stop bar, thus providing an effective notice to a distracted driver that might commonly miss the stationary rail-crossing sign.

The J2735 MAP message standard identifies the intersections it represents under a sequence of ***IntersectionGeometry*** objects, that includes among other things a unique identifier (***IntersectionReferenceID***), the latitude / longitude coordinates (***refPoint***), and ***LaneList***, which is a sequence of lane information. To capture the presence of a train, the ***LaneList*** must include vehicle lanes entering and exiting the HRI, plus a non-traditional lane that represents the railroad tracks. The key component within each lane structure includes an identifier unique to this intersection (***LaneID***), some attributes identifying the direction of the lane (***LaneDirection***), and the type of vehicle(s) using the lane (***LaneTypeAttributes***), which should be set to ***vehicle*** for the vehicle approach lanes and ***trackedVehicle*** for the rail lane (SAE International, 2016).

Each node in the lanes is encoded using coordinate (x, y) offsets from the previous node. This limits the size of the MAP file being broadcast. See Appendix B.

Finally, the available sequence of ***Connection*** attributes for each lane in the MAP message can be used to identify several important relationships in the traffic flow. For example, the ***ConnectingLane*** object identifies both an adjacent lane that this one connects to (***LaneID***) and the allowed vehicle maneuver (***AllowedManeuvers***) between them, such as ***maneuverStraightAllowed***, ***maneuverLeftAllowed***, ***maneuverRightAllowed*** and/or ***maneuverUTurnAllowed***. Additionally, the connecting lane is mapped to a "signal group" identifier (***SignalGroupID***) that indicates the traffic signal controller (TSC) signal phase or overlap that controls the maneuver for this connection (SAE International, 2016).

Message Creation

The MAP message XML or JSON format may be built by hand, but it takes specialized software in order to convert that over to the ASN.1 encoded byte structure, which for the J2735 2006 release uses the unaligned-packed encoding rules (UPER) of a ubiquitous MessageFrame envelope that specifies the specific message enclosed in order to decode it. Therefore, to avoid extra work in the encoding of the message, the ISD Builder Tool (ISD Builder Tool for J2735 3/2016, n.d.) is a web application designed to assist in building the MAP message contents and encoding them. This section details instructions to assist in this process, as a supplement to the on-line help on the ISD page.

Parent Map

The ISD tool conceptually has a *parent* map file that identifies the global configuration of the HRI, which primarily consists of the ***refPoint***, and a *child* map that constructs the ***LaneList*** and ***Connection*** objects. The parent map can be built under the ***File->New Parent Map*** option. The two tools available under the parent map builder are the ***Reference Point Marker*** and the ***Verified Point Marker***. Add the ***Reference Point Marker*** to the point that will represent the center of the HRI. Whereas the Latitude, Longitude and Elevation options should remain the same, the Intersection Name, Intersection ID and Master Lane Width fields may be customized. Next, place a ***Verified Point Marker*** on the specific location on the MAP which ideally, should be a GNSS point that was professionally surveyed. This time replace the ***Verified Latitude, Verified Longitude*** and ***Verified Elevation*** fields with the resultant surveyed values.

The parent map is complete and can be saved using ***File->Save***. A revision number is added to the file name in order to keep track of future updates, such as to the verified points. The resulting JSON file can be reloaded into the editor using ***File->Open Parent Map***.

Child Map

A new child map is created with the ***File->New Child Map*** option. The child map in the ISD tool is always associated with some parent map, thus a dialog opens up to select the parent map to use. In particular, the reference GNSS points built into the parent map are used to calculate the node locations for the lanes. Changes to that parent map are not automatically reflected in the child map. Instead, they must be manually updated under the child map using the ***File->Update Child Markers*** option.

Both markers from the parent map can now be seen in the child map. The ***Reference Point*** should be used as the relative position for constructing the lanes in the map. The toolbox for the child map editor consists of Approach, Lane, and Measure. An approach is a container for lane, and in general there is a one-to-one mapping of approach to lane. The initial step to constructing the lanes for the MAP in the ISD is to build the Approach. See the on-line help for specific drawing instructions. The actual Approach can be a small box big enough to hold a single lane node near the HRI reference. For example Figure 2, shows two approach boxes, one for an ingress lane and one for an egress lane in the opposite direction.

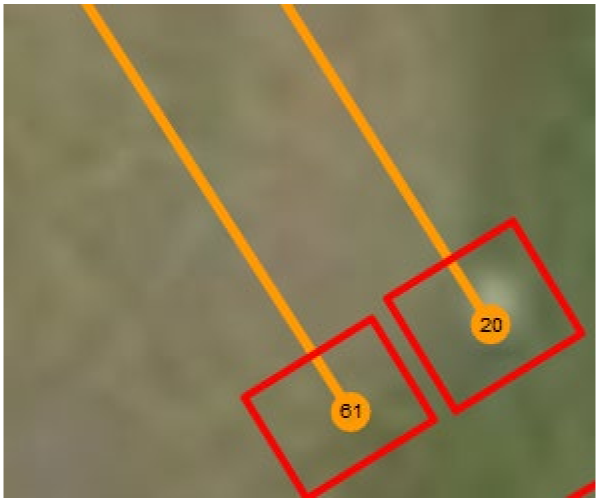

Figure 2. Two approaches for two lane nodes

Every Approach has two attributes: the type and the ID. An approach type can be Ingress (incoming), Egress (outgoing), Both or None (the approach type None means that it does not support travel such as medians, curbs, etc.). Obviously, the lanes used by the vehicle should be exclusively Ingress or Egress. However, the railroad track lane can either be directional if there are directional tracks, or they can be combined into a single approach of type Both.

An approach ID can really be anything, but traffic engineers tend to follow simple numbering schemes while configuring traffic controller phases that denote the directionality of movement. Left turn movements are assigned odd numbers, while through movements are assigned even numbers. Phase 2 is usually assigned to the major streets, and the rest are numbered clockwise by twos around the intersection. More generally, this can be applied to the directions on a compass as seen in Figure 3.

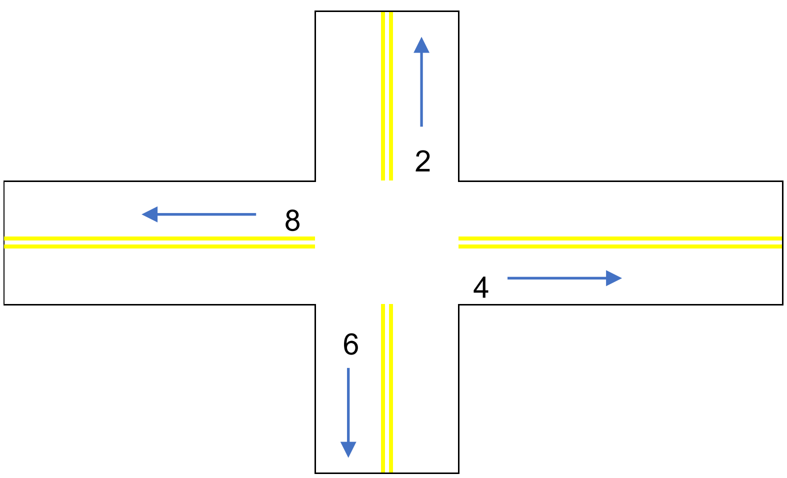

Figure 3. Basic Approach Numbering

A complementary approach ID used for turning lanes should be set so that the sum of the two are either 7 or 11 (for numbers 7 and above). Thus, a 5 also applies N approach, since 2 (N) + 5 = 7. Likewise, 7 is an E approach since 4 (E) + 7 = 11. Thus, the odd number approaches are (N, S, E, W): 5, 1, 7, 3. Variations of this numbering scheme has been used in previous software applications to simplify calculations, but currently the directionality for RCVW enabled vehicles is determined by the heading of the vehicle in relation to the HRI location. Therefore, this numbering is optional, although still highly recommended.

After the approach is drawn, the lane nodes are created using the available Lane tool. The first node should be closest to the HRI, and each subsequent node should move further away. Node positions are generally only set to build a smoother geometry for the lane, such as adding a dense population of nodes along the curve the road. The Lane Type and Lane Number are key attributes that should be set on the first node of the lane. The type should be ***Vehicle*** for every type of automobile lane, including the tracks, but the MAP may also define crosswalk or bicycle lanes. The numbering of the lane is recommended to be a two-digit value with the first digit being the same as the approach. For example, the lane 61 from Figure 2 is the first south-bound lane. In that same picture, lane 20 represents the egress lane that is immediately across from lane 21, the ingress.

Train tracks are a special case of a vehicle lane that requires a Shared With attribute setting to ***(8) Tracked Vehicle***. As stated previously, and generally speaking, there is one lane in an approach. However, since the RCVW software is built upon the V2X Hub intersection concept which requires separate ingress and egress lanes for a thru maneuver, the train tracks must be split on either side of the HRI center. Therefore, the example below as seen in Figure 4 includes two separate sections of the tracks (lanes 40 and 41) within the same approach. The software simply assumes the tracks span directly through the HRI.

Figure 4. A simple HRI with approach lanes and tracks

Thus far, only the static position and geometry has been defined for the child map. There is additional information that must be configured into the lanes that help define the SPaT relationships. Under the Lane Configuration of the first lane node, there is a SPaT tab and a Connections tab. The former is for static phase information such as a stop sign or a permanent flashing light. The Connections tab is more useful in a dynamic situation. Select the ingress approach lane (e.g. lanes 21 and 61), then add a new connection under that tab. The connection ID can be sequential, but the “To” Lane Number must be the lane number of the direct egress lane on the other side of the track (e.g. lanes 20 and 60). Additionally, a signal group ID needs to be set for the connection. It is important that the approach lanes are assigned a distinct signal group ID from the track lanes. For example, the signal group 1 can be for the tracks and signal group 2 for the approach lanes. The builder tool on the editor contains a set of lane feature signs that can be dragged over to the allowed maneuvers. For the example in Figure 4, the connection from lane 21 to 20 should be a straight-thru maneuver. See Figure 5 for a completed connection.

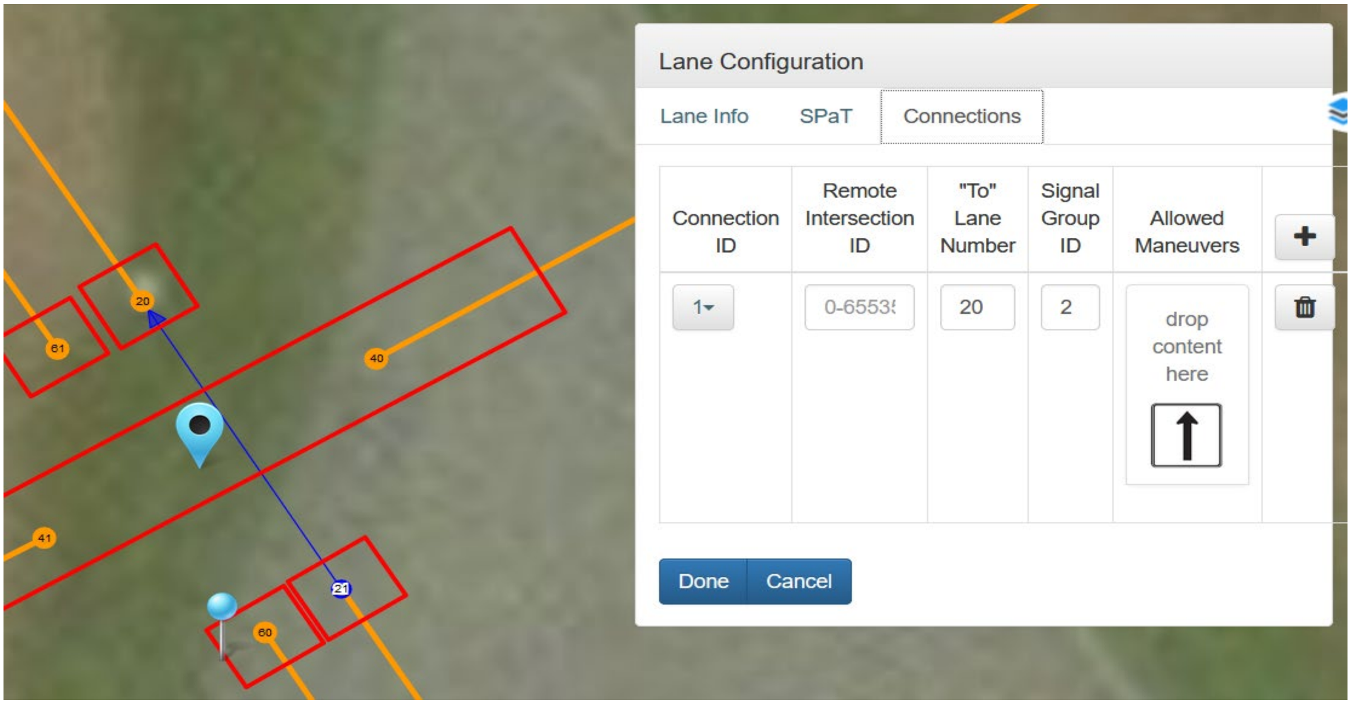

Figure 5. Approach lane connection over the tracks

After adding the approach lane maneuvers, the same process needs to be applied to the tracks, only with a different signal group, as shown in Figure 6.

Figure 6. Railroad track lane connection

After the connections are built, the child map should be saved with revision number by selecting ***File->Save***.

Finally, the resultant MAP must be encoded by the ISD tool for use in V2X Hub. This is done with the ***Tools->Encoder*** option. When used with the MAP Plugin, the Message Type must be set to ***Frame+Map*** and the Node Offsets should be ***Tight***. If the crossing is significantly graded, the ***Enable Elevation?*** option must be marked as true. When the ***Encode*** button is pressed, the UPER Hex field will have the exact J2735 MapData message output that is to be broadcast. This value must be copied from the browser window and saved to a file manually. Note that the name of the file must end with a **.txt** extensionA readable version of this encoded message can be verified on the RBS system running the V2X Hub software by executing the *j2735dump* command using the file as input. An example XML encoded version of this file can be found in Appendix B.

Message Broadcast

The MAP message generated out of the ISD tool is written to a file under the MAP Plugin directory on the RBS equipment that is running V2X Hub. This is done via the file upload process using the V2I Hub Administration Portal (Gibbs & Hohe, 2018). Using the administration portal, the MAP Plugin configuration key MAP_Files must be updated to reflect the uploaded file (Zink & Baumgardner, 2018). The file name must have a **.txt** extension for the MAP Plugin to recognize that the input file has the precise UPER-encoded message (Zink & Baumgardner, 2018). The Frequency for the MAP Plugin to send this message is 1000 ms since the required frequency for a MAP message is one time per second, or 1 Hz (Zink & Baumgardner, 2018). The DSRC Message Manager configuration may also require updates to the destination IP address for the specific RSU used in the broadcast (Zink & Baumgardner, 2018).

3 Standard Operating Procedure for SPaT

Message Contents

For a SPaT message, the ***IntersectionState*** object is used to pass the dynamic state information within an intersection. The ***IntersectionReferenceID*** field specifies the identifier of the intersection as defined in the MAP message. Likewise, each ***MovementState*** object contains the signal group identifier (***SignalGroupID***) defined in the MAP and a ***MovementEventList*** for the current state. The project team manipulated the ***MovementPhaseState*** to signify the state of the virtual light for the signal group maneuver. For example, ***Stop-And-Remain*** represents a normal red light and ***Protected-Movement-Allowed*** a normal green. Whereas a conventional SPaT application uses state data for each signal group directly from the TSC, the HRI status software running on RCVW RBS transitions each signal group to its appropriate ***MovementPhaseState*** based on the status of the HRI infrastructure equipment. This represents whether or not a train is approaching based on the phase state of the signal group.

Message Creation

The phase state is automatically injected into the SPaT message by the HRI Status Plugin. There are two possible configurations that can be used to determine the HRI pre-emption signal state. The first is a digital interface developed by the Institute of Electrical and Electronics Engineers (IEEE), which employs the TIA/EIA-422 serial communication electrical interconnection interface standard. The second utilizes the existing discrete voltage common to the railway train detection systems.

IEEE 1570 Signaling

The IEEE 1570 messaging code is built into the HRI Status Plugin. Cabling interconnects the IEEE 1570 device to the Neousys POC-351VT computing platform of the RBS. The Neousys POC-351VT has multiple COM serial ports, each having a DB-9 male connector, that can be configured in the BIOS as a TIA/EIA-422 terminus. The HRI pre-emption messages received by the application are decoded and translated and the resultant status set inside the outgoing SPaT. If no messages are received by the plugin, the HRI is assumed to be active, i.e. a train present.

Voltage-based Signaling

The Neousys POC-351VT also has a discrete Digital Input/Output (DIO) feature. Cabling interconnects the HRI status signal, and its return, to the Digital Input/Output (DIO) via a DB-15 connector. Input pins are (either 1, 2, 10 or 11 for the signal), and (either pin 3 or 9 for the return). The signal is active low, so a drop in voltage from high to low will indicate that a train is present. Thus, the input should be grounded when the signal is disconnected or lost, indicating the safe state of presumed train presence. Note that pin chosen for the voltage must be configured in the HRI Status Plugin [see RCVW Standard Operating Procedure - Hardware and Software Configuration (Baumgardner, Paselsky, & Sanchez-Badillo, 2021)].

Message Broadcast

The SPaT message by default should be configured in the DSRC Message Manager, so only the destination may need to be changed for broadcast (Zink & Baumgardner, 2018). However, the HRI Status Plugin itself requires its own set of configuration values to operate correctly. First, the Frequency field must be 100 ms since the SPaT frequency is expected at ten times per second (10 Hz). Next, the Intersection ID must be filled in with the same ***IntersectionReferenceID*** that was defined in the MAP message. There is also an associate Intersection Name field that may be used to give a readable name for this HRI. The Lane Map field is required to identify the signal groups used for the train track and the one (or more) used for the vehicle lanes, as a comma-separate list. For example, if signal group 1 is the railway and group 2 is for the approach lanes, this value should read: ***1:tracked,2:vehicle***.

The plugin also must be set up to either run using the IEEE 1570 interface, or the voltage-based signaling. The IEEE 1570 interface is selected by setting the Port Name field to the TIA/EIA-422 COM device used. If this value is missing, then the plugin assumes there is a voltage signal on the assigned DIO pin. The RailPinNumber determines which DIO pin to read from. Note that the pin numbers on the device may be normally considered 1-15, whereas the plugin considers them 0-14. So, the default value of 0 means that DIO pin 1 of the device will be used. If the Port Name is used, then the two fields Monitor Frequency and Serial Data Timeout are also used. The former indicates the frequency for checking the interface, in milliseconds, and the latter sets a maximum number of lapsed milliseconds before assuming the messages are missing.

The example SPaT messages in Appendix C and D demonstrate the conditions for the HRI active and not active states for the example MAP in Appendix B. Note that these can be obtained from the V2X Hub log or from a Paquet Capture (PCAP) from the DSRC radios and decoded with the *j2735dump* program.

4 Standard Operating Procedure for RTCM Corrections

Message Contents

The RTCM Correction message is one of the more straight-forward structures within the J2735 message set. This is primarily because the RTCM messages themselves have been well defined for some time, and thus their use over DSRC broadcast effectively became a pass-through. There is a field that indicates what version of RTCM is used for the enclosed messages (***rev***), plus a sequence of 1Kbyte octet strings (***msgs***). The ***msgs*** are inserted verbatim from the RTCM correction message generated by the NTRIP caster or some other means, subjected only to the J2735 encoding process.

Message Creation

The RTCM Plugin by default will attempt to connect to an NTRIP caster to receive the RTCM correction. The J2735 message is created automatically from the incoming corrections. Alternatively, a Location Plugin (see Figure 1) can be added to the RBS and connected to a fixed GNSS base station receiver located near the HRI. With a correctly configured base station connected over Universal Serial Bus (USB), the Location Plugin can obtain the correction messages directly from the receiver that is generating them. These RTCM messages are then automatically forwarded to the RTCM Plugin in order to create the J2735 message for broadcast. Note that this base station configuration was verified in the RCVW system during field test activities using a u-Blox ZED-F9P GNSS receiver.

Message Broadcast

For proper receipt of corrections from NTRIP, the RTCM Plugin should be configured with the Endpoint IP and Endpoint Port of the NTRIP caster, along with the login information of Username, Password and Mountpoint. Most Mountpoint options map to a virtual reference station (VRS) within the base station networks, thus some GNSS position pointer must be supplied to obtain the closest station to the RBS. Therefore, the Location plugin must be running on the RBS with the parameter SendRawNMEA set to true in order to pass a current GNSS string for locating the proper VRS. If a local base station configuration is being used, then the Location Plugin requires no specific configuration, but the SendRawNMEA value should be set to false for performance reasons. The RTCM Version in general should be set to ***3.3*** for real-time kinematics (RTK) corrections, which is the expected Differential GNSS mode used with RCVW.

Once the RTCM Plugin is configured correctly, then J2735 RTCM type messages begin to be generated. However, the DSRC message manager still must be configured to forward PSID 0x8000 for the RTCM type (Zink & Baumgardner, 2018), as it may not be the default. If the RTCM correction message fails to be sent from the RSU, this missing configuration is likely the cause.

5 Impacts to RCVW VBS

The previous sections described how to setup the roadside equipment for message broadcast. The primary function of the RCVW in-vehicle application is to receive those messages and decide if and when an alert should be issued. Many options in the plugin configuration go into this decision that are out of scope of this SOP [see RCVW Standard Operating Procedure - Hardware and Software Configuration (Baumgardner, Paselsky, & Sanchez-Badillo, 2021)]. However, some key infrastructure settings contribute to the proper operation of the system as a whole but were added for convenience to the on-board configuration.

HRI Distance

The RCVW system requirements state that the application must produce an error when a DSRC broadcast is expected but not received. The dilemma here is that there is no existing infrastructure to update the HRI location-and-ID database of the RBS.

To resolve this dilemma, the RCVW Plugin running within the vehicle is pre-configured with locations of the known HRIs. This is a short-term solution that could easily be updated to retrieve the same list from some web service during periods of Internet connectivity. The HRI Locations parameter defines an array of HRIs in JSON form, indicating at minimum the Latitude, Longitude and HRIName for each. For example, the data from the MAP in Appendix B can be extracted into this parameter:

```
{ "HRIs": [  {"Latitude":40.3157403, "Longitude":-83.5570125, "HRIName":"TRC Railway 1"}] }
```

The RCVW application also must know at what maximum distance (in meters) away from the listed HRIs should an alert be issued. This is set under the Distance to HRI parameter. Once the vehicle comes within that distance from the TRC Railway 1, (for example), then it will expect to receive messages over the DSRC radio. If not, the system is considered to be in a failure state. Note that the Distance to HRI value should be more than the longest lane length in the map. A typical value entered in this parameter might be 500, indicating 500 meters. This value should be adjusted depending on the characteristics of each HRI approach.

Works Cited

AASHTO. (2018). *A Policy on Geometric Design of Highways and Streets* (7th ed.). Atlanta, GA: AASHTO.

Baumgardner, G., Paselsky, B., & Sanchez-Badillo, A. (2021). *RCVW Standard Operating Procedure - Hardware and Software Configuration.* Washington, D.C: Federal Railroad Administration.

Federal Highway Administration. (2009). *Manual on Uniform Traffic Control Devices for Streets and Highways.* Washington, D.C.: Federal Highway Administration.

Gibbs, W., & Hohe, V. (2018). *V2I Hub Administration Portal User Guide.* Washington, D.C.: Federal Highway Administration.

ISD Builder Tool for J2735 3/2016. (n.d.). Retrieved from connectedvcs.com: https://webapp.connectedvcs.com/isd/

SAE International. (2016). *J2735: Dedicated Short Range Communications (DSRC) Message Set Directory.* Warrendale, PA: SAE International.

Zink, G., & Baumgardner, G. (2018). *V2I Hub Plugins.* Washington, D.C.: Federal Highway Administration.

APPENDIX A. List of Acronyms and Abbreviations

ASN.1	Abstract Syntax Notation One
CV	Connected Vehicle
DGNSS	Differential Global Navigation Satellite System
DIO	Digital Input/Output
DSRC	Dedicated Short-Range Communication
GNSS	Global Navigation Satellite Systems
HRI	Highway-Rail Intersection
IEEE	Institute of Electrical and Electronics Engineers
ISD	Intersection Situation Data
JSON	JavaScript Object Notation
MAP	Roadway Geometry and Attribute Data (a.k.a., GID)
MUTCD	Manual on Uniformed Traffic Control Devices
NTRIP	Network Transport of RTCM via Internet Protocol
OBU	On-board Unit (DSRC radio in VBS)
PCAP	Paquet Capture
RBS	Roadside-based Subsystem (an RCVW subsystem)
RCVW	Rail Crossing Violation Warning (warning message)
RSU	Roadside Unit (DSRC radio in RBS)
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SPaT	Signal Phase and Timing
TSC	Traffic Signal Controller
UDP	User Datagram Protocol
UPER	Unaligned-Packed Encoding Rules
VBS	Vehicle-based Subsystem (an RCVW subsystem)
VRS	Virtual Reference Station
V2I	Vehicle to Infrastructure
V2X	Vehicle to Everything
XML	Extensible Marker Language

Appendix B: Example MAP


```
<?xml version="1.0" encoding="utf-8"?>
<MapData>
        <msgIssueRevision>10</msgIssueRevision>
        <layerType>
                <intersectionData/>
        </layerType>
        <layerID>0</layerID>
        <intersections>
                <IntersectionGeometry>
                        <id>
                                <id>40249</id>
                        </id>
                        <revision>10</revision>
                        <refPoint>
                                <lat>403157530</lat>
                                <long>-835570125</long>
                        </refPoint>
                        <laneWidth>366</laneWidth>
                        <laneSet>
                                <GenericLane>
                                        <laneID>60</laneID>
                                        <egressApproach>6</egressApproach>
                                        <laneAttributes>
                                                <directionalUse>01</directionalUse>
                                                <sharedWith>0000000000</sharedWith>
                                                <laneType>
                                                        <vehicle>00000000</vehicle>
                                                </laneType>
                                        </laneAttributes>
                                        <nodeList>
                                                <nodes>
                                                        <NodeXY>
                                                                <delta>
                                                                        <node-XY2>
                                                                                <x>247</x>
                                                                                <y>-670</y>
                                                                        </node-XY2>
                                                                </delta>
                                                        </NodeXY>
                                                        <NodeXY>
                                                                <delta>
                                                                        <node-XY3>
                                                                                <x>906</x>
                                                                                <y>-1448</y>
                                                                        </node-XY3>
                                                                </delta>
                                                        </NodeXY>
                                                        <NodeXY>
                                                                <delta>
                                                                        <node-XY3>
                                                                                <x>1020</x>
                                                                                <y>-1584</y>
                                                                        </node-XY3>
                                                                </delta>
                                                        </NodeXY>
                                                        <NodeXY>
```

```
                <delta>
                        <node-XY3>
                                <x>1123</x>
                                <y>-1754</y>
                        </node-XY3>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY3>
                                <x>1123</x>
                                <y>-1732</y>
                        </node-XY3>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY4>
                                <x>2189</x>
                                <y>-3424</y>
                        </node-XY4>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY3>
                                <x>1106</x>
                                <y>-1726</y>
                        </node-XY3>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY4>
                                <x>1716</x>
                                <y>-2680</y>
                        </node-XY4>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY5>
                                <x>3990</x>
                                <y>-6194</y>
                        </node-XY5>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY4>
                                <x>2018</x>
                                <y>-3117</y>
                        </node-XY4>
                </delta>
        </NodeXY>
        <NodeXY>
                <delta>
                        <node-XY4>
                                <x>1921</x>
                                <y>-3015</y>
```

```
                    </node-XY4>
                </delta>
            </NodeXY>
        </nodes>
    </nodeList>
</GenericLane>
<GenericLane>
    <laneID>21</laneID>
    <ingressApproach>5</ingressApproach>
    <laneAttributes>
        <directionalUse>10</directionalUse>
        <sharedWith>0000000000</sharedWith>
        <laneType>
            <vehicle>00000000</vehicle>
        </laneType>
    </laneAttributes>
    <nodeList>
        <nodes>
            <NodeXY>
                <delta>
                    <node-XY2>
                        <x>534</x>
                        <y>-491</y>
                    </node-XY2>
                </delta>
            </NodeXY>
            <NodeXY>
                <delta>
                    <node-XY3>
                        <x>1203</x>
                        <y>-1891</y>
                    </node-XY3>
                </delta>
            </NodeXY>
            <NodeXY>
                <delta>
                    <node-XY3>
                        <x>1231</x>
                        <y>-1913</y>
                    </node-XY3>
                </delta>
            </NodeXY>
            <NodeXY>
                <delta>
                    <node-XY4>
                        <x>2479</x>
                        <y>-3849</y>
                    </node-XY4>
                </delta>
            </NodeXY>
            <NodeXY>
                <delta>
                    <node-XY5>
                        <x>4936</x>
                        <y>-7693</y>
                    </node-XY5>
                </delta>
            </NodeXY>
            <NodeXY>
                <delta>
```

```
                                    <node-XY5>
                                        <x>3773</x>
                                        <y>-5865</y>
                                    </node-XY5>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY5>
                                        <x>3790</x>
                                        <y>-5922</y>
                                    </node-XY5>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY5>
                                        <x>3808</x>
                                        <y>-5916</y>
                                    </node-XY5>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY4>
                                        <x>1835</x>
                                        <y>-2856</y>
                                    </node-XY4>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY4>
                                        <x>1693</x>
                                        <y>-2612</y>
                                    </node-XY4>
                                </delta>
                            </NodeXY>
                        </nodes>
                    </nodeList>
                    <connectsTo>
                        <Connection>
                            <connectingLane>
                                <lane>20</lane>

<maneuver>100000000000</maneuver>
                            </connectingLane>
                            <signalGroup>2</signalGroup>
                            <connectionID>1</connectionID>
                        </Connection>
                    </connectsTo>
                </GenericLane>
                <GenericLane>
                    <laneID>41</laneID>
                    <name>Rail W</name>
                    <ingressApproach>4</ingressApproach>
                    <egressApproach>4</egressApproach>
                    <laneAttributes>
                        <directionalUse>11</directionalUse>
                        <sharedWith>0000000010</sharedWith>
```

```
                                                <laneType>
                                                        <vehicle>00000000</vehicle>
                                                </laneType>
                                        </laneAttributes>
                                        <nodeList>
                                                <nodes>
                                                        <NodeXY>
                                                                <delta>
                                                                        <node-XY2>
                                                                                <x>-584</x>
                                                                                <y>-279</y>
                                                                        </node-XY2>
                                                                </delta>
                                                        </NodeXY>
                                                        <NodeXY>
                                                                <delta>
                                                                        <node-XY6>
                                                                                <x>-10760</x>
                                                                                <y>-6003</y>
                                                                        </node-XY6>
                                                                </delta>
                                                        </NodeXY>
                                                        <NodeXY>
                                                                <delta>
                                                                        <node-XY6>
                                                                                <x>-10601</x>
                                                                                <y>-5717</y>
                                                                        </node-XY6>
                                                                </delta>
                                                        </NodeXY>
                                                </nodes>
                                        </nodeList>
                                        <connectsTo>
                                                <Connection>
                                                        <connectingLane>
                                                                <lane>40</lane>

<maneuver>100000000000</maneuver>
                                                        </connectingLane>
                                                        <signalGroup>1</signalGroup>
                                                        <connectionID>1</connectionID>
                                                </Connection>
                                        </connectsTo>
                                </GenericLane>
                                <GenericLane>
                                        <laneID>40</laneID>
                                        <name>Rail E</name>
                                        <ingressApproach>4</ingressApproach>
                                        <egressApproach>4</egressApproach>
                                        <laneAttributes>
                                                <directionalUse>11</directionalUse>
                                                <sharedWith>0000000010</sharedWith>
                                                <laneType>
                                                        <vehicle>00000000</vehicle>
                                                </laneType>
                                        </laneAttributes>
                                        <nodeList>
                                                <nodes>
                                                        <NodeXY>
                                                                <delta>
```

```
                                    <node-XY2>
                                        <x>665</x>
                                        <y>463</y>
                                    </node-XY2>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY6>
                                        <x>10915</x>
                                        <y>6484</y>
                                    </node-XY6>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY6>
                                        <x>10955</x>
                                        <y>6756</y>
                                    </node-XY6>
                                </delta>
                            </NodeXY>
                        </nodes>
                    </nodeList>
                    <connectsTo>
                        <Connection>
                            <connectingLane>
                                <lane>40</lane>

<maneuver>100000000000</maneuver>
                            </connectingLane>
                            <signalGroup>1</signalGroup>
                            <connectionID>1</connectionID>
                        </Connection>
                    </connectsTo>
                </GenericLane>
                <GenericLane>
                    <laneID>61</laneID>
                    <ingressApproach>1</ingressApproach>
                    <laneAttributes>
                        <directionalUse>10</directionalUse>
                        <sharedWith>0000000000</sharedWith>
                        <laneType>
                            <vehicle>00000000</vehicle>
                        </laneType>
                    </laneAttributes>
                    <nodeList>
                        <nodes>
                            <NodeXY>
                                <delta>
                                    <node-XY2>
                                        <x>-534</x>
                                        <y>503</y>
                                    </node-XY2>
                                </delta>
                            </NodeXY>
                            <NodeXY>
                                <delta>
                                    <node-XY5>
                                        <x>-3963</x>
```

```
                                                                                &lt;y&gt;6105&lt;/y&gt;
                                                                        &lt;/node-XY5&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                        &lt;NodeXY&gt;
                                                                &lt;delta&gt;
                                                                        &lt;node-XY5&gt;
                                                                                &lt;x&gt;-4013&lt;/x&gt;
                                                                                &lt;y&gt;6302&lt;/y&gt;
                                                                        &lt;/node-XY5&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                        &lt;NodeXY&gt;
                                                                &lt;delta&gt;
                                                                        &lt;node-XY6&gt;
                                                                                &lt;x&gt;-7888&lt;/x&gt;
                                                                                &lt;y&gt;12252&lt;/y&gt;
                                                                        &lt;/node-XY6&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                        &lt;NodeXY&gt;
                                                                &lt;delta&gt;
                                                                        &lt;node-XY5&gt;
                                                                                &lt;x&gt;-4708&lt;/x&gt;
                                                                                &lt;y&gt;7346&lt;/y&gt;
                                                                        &lt;/node-XY5&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                        &lt;NodeXY&gt;
                                                                &lt;delta&gt;
                                                                        &lt;node-XY5&gt;
                                                                                &lt;x&gt;-4290&lt;/x&gt;
                                                                                &lt;y&gt;6404&lt;/y&gt;
                                                                        &lt;/node-XY5&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                &lt;/nodes&gt;
                                        &lt;/nodeList&gt;
                                        &lt;connectsTo&gt;
                                                &lt;Connection&gt;
                                                        &lt;connectingLane&gt;
                                                                &lt;lane&gt;60&lt;/lane&gt;

&lt;maneuver&gt;100000000000&lt;/maneuver&gt;
                                                        &lt;/connectingLane&gt;
                                                        &lt;signalGroup&gt;2&lt;/signalGroup&gt;
                                                        &lt;connectionID&gt;1&lt;/connectionID&gt;
                                                &lt;/Connection&gt;
                                        &lt;/connectsTo&gt;
                                &lt;/GenericLane&gt;
                                &lt;GenericLane&gt;
                                        &lt;laneID&gt;20&lt;/laneID&gt;
                                        &lt;egressApproach&gt;2&lt;/egressApproach&gt;
                                        &lt;laneAttributes&gt;
                                                &lt;directionalUse&gt;01&lt;/directionalUse&gt;
                                                &lt;sharedWith&gt;0000000000&lt;/sharedWith&gt;
                                                &lt;laneType&gt;
                                                        &lt;vehicle&gt;00000000&lt;/vehicle&gt;
                                                &lt;/laneType&gt;
                                        &lt;/laneAttributes&gt;
```

```
                                        &lt;nodeList&gt;
                                                &lt;nodes&gt;
                                                        &lt;NodeXY&gt;
                                                                &lt;delta&gt;
                                                                        &lt;node-XY2&gt;
                                                                                &lt;x&gt;-215&lt;/x&gt;
                                                                                &lt;y&gt;702&lt;/y&gt;
                                                                        &lt;/node-XY2&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                        &lt;NodeXY&gt;
                                                                &lt;delta&gt;
                                                                        &lt;node-XY6&gt;
                                                                                &lt;x&gt;-16183&lt;/x&gt;
                                                                                &lt;y&gt;25255&lt;/y&gt;
                                                                        &lt;/node-XY6&gt;
                                                                &lt;/delta&gt;
                                                        &lt;/NodeXY&gt;
                                                &lt;/nodes&gt;
                                        &lt;/nodeList&gt;
                                &lt;/GenericLane&gt;
                        &lt;/laneSet&gt;
                &lt;/IntersectionGeometry&gt;
        &lt;/intersections&gt;
&lt;/MapData&gt;
```

Appendix C: HRI Active SPaT Message


```
<?xml version="1.0" encoding="utf-8"?>
<SPAT>
	<intersections>
		<IntersectionState>
			<name>TRC Flat Rail</name>
			<id>
				<id>40249</id>
			</id>
			<revision>1</revision>
			<status>0000000010000000</status>
			<moy>30011</moy>
			<timeStamp>55102</timeStamp>
			<states>
				<MovementState>
					<signalGroup>1</signalGroup>
					<state-time-speed>
						<MovementEvent>
							<eventState>
								<protected-Movement-Allowed/>
							</eventState>
							<timing>

<minEndTime>32850</minEndTime>

<maxEndTime>32850</maxEndTime>
							</timing>
						</MovementEvent>
					</state-time-speed>
				</MovementState>
				<MovementState>
					<signalGroup>2</signalGroup>
					<state-time-speed>
						<MovementEvent>
							<eventState>
								<stop-And-Remain/>
							</eventState>
							<timing>

<minEndTime>32850</minEndTime>

<maxEndTime>32850</maxEndTime>
							</timing>
						</MovementEvent>
					</state-time-speed>
				</MovementState>
			</states>
		</IntersectionState>
	</intersections>
</SPAT>
```

Appendix D: HRI Inactive SPaT Message


```xml
<?xml version="1.0" encoding="utf-8"?>
<SPAT>
	<intersections>
		<IntersectionState>
			<name>TRC Flat Rail</name>
			<id>
				<id>40249</id>
			</id>
			<revision>1</revision>
			<status>0000000010000000</status>
			<moy>30011</moy>
			<timeStamp>55102</timeStamp>
			<states>
				<MovementState>
					<signalGroup>1</signalGroup>
					<state-time-speed>
						<MovementEvent>
							<eventState>
								<stop-And-Remain/>
							</eventState>
							<timing>

<minEndTime>32850</minEndTime>

<maxEndTime>32850</maxEndTime>
							</timing>
						</MovementEvent>
					</state-time-speed>
				</MovementState>
				<MovementState>
					<signalGroup>2</signalGroup>
					<state-time-speed>
						<MovementEvent>
							<eventState>
								<permissive-Movement-
Allowed/>
							</eventState>
							<timing>

<minEndTime>32850</minEndTime>

<maxEndTime>32850</maxEndTime>
							</timing>
						</MovementEvent>
					</state-time-speed>
				</MovementState>
			</states>
		</IntersectionState>
	</intersections>
</SPAT>
```

U.S. Department of Transportation
Federal Railroad Administration
1200 New Jersey Avenue, SE
Washington, DC 20590

U.S. Department of Transportation