SPaT V2I Interface for Red Light Violation Warning Concept of Operations

Version 20200409

April 2020

Prepared by:
Cooperative Automated Transportation (CAT) Coalition - IOO/OEM Forum

Primary Author:
Ray Starr, Minnesota Department of Transportation

Contents

1 Introduction

1.1 Background

Vehicle to Infrastructure (V2I) communications can improve traffic safety by enabling vehicles to utilize information from the roadside, such as from traffic signals, to support the driver in the driving task or to support automated driving systems. One V2I application that has progressed to a certain level of maturity in research and developmental testing is Red Light Violation Warning (RLVW).

Standards exist defining the communications technology and data messages between an equipped traffic signal and equipped vehicle to support RLVW. IEEE 802.11p defines Dedicated Short Range Communications (DSRC), based on WiFi standards. IEEE 1609 defines security and other aspects of communications. SAE J2735 defines Signal Phase and Timing (SPaT) and MAP messages that describe intersection geometry, traffic signal status, traffic signal state and traffic signal timing to a vehicle near an equipped intersection. Many of these standards have optional data elements and multiple allowed methods for conveying information. These options can result in different intersections being differently equipped to provide MAP and SPaT data in a manner that complies with the standards but is not interoperable. In order for RLVW to become widespread in production vehicles and traffic signals, it is important to apply the standards uniformly across North America.

The Crash Avoidance Metrics Partners LLC (CAMP) as part of the Infrastructure Owner Operator / Original Equipment Manufacturer (IOO/OEM) Forum of the Cooperative Automated Transportation (CAT) Coalition has performed field testing of RLVW at multiple intersections that are equipped to provide SPaT and MAP messages. As a result of this testing, CAMP has identified and documented verification requirements, test procedures, unexpected results, and inconsistencies in the application of the standard. Documentation of these findings is distributed across many individual documents identified in the Referenced Documents section of this Concept of Operations (ConOps). None of the individual documents provides a comprehensive view of the requirements that have evolved for supporting RLVW.

1.2 Purpose

The purpose of this ConOps and its associated System Requirement Specification (SRS) is to consolidate the findings of the several IOO/OEM forum documents, discussions that have been held and additional observations into a more structured and comprehensive form for consideration in future standards or guidance creation efforts by others.

This ConOps is focused on the SPaT V2I Interface for RLVW and is not a ConOps for a complete SPaT infrastructure system at a specific intersection. Because of this focused purpose of the ConOps, it does not address all of the user needs of the system, only those of the SPaT V2I Interface for RLVW. Other applications in addition to RLVW would entail additional needs beyond those included in this ConOps. The IOO implementing a SPaT enabled intersection may want to consider implementing other applications along with RLVW.

1.3 Document Overview

This ConOps provides an overview of the context for the SPaT V2I Interface for RLVW, the RLVW application to be supported, users and user needs, an operational scenario for the SPaT V2I Interface for RLVW, and operational concepts. The companion document to this ConOps is the SPaT V2I Interface for Red Light Violation Warning System Requirements Specification, in which system requirements are defined and traced back to the user needs.

1.4 Context of SPaT V2I Interface for RLVW

The SPaT V2I Interface for RLVW exists in a larger context of other functional components that make up the SPaT-Enabled V2I Connected Vehicle System. The SPaT V2I Interface for RLVW that is the focus of this ConOps is the interface between the SPaT Infrastructure System and the SPaT Vehicle System. Figure 1 SPaT Enabled V2I Connected Vehicle Systemillustrates the context of the SPaT V2I Interface for RLVW within the complete SPaT Enabled V2I Connected Vehicle System.

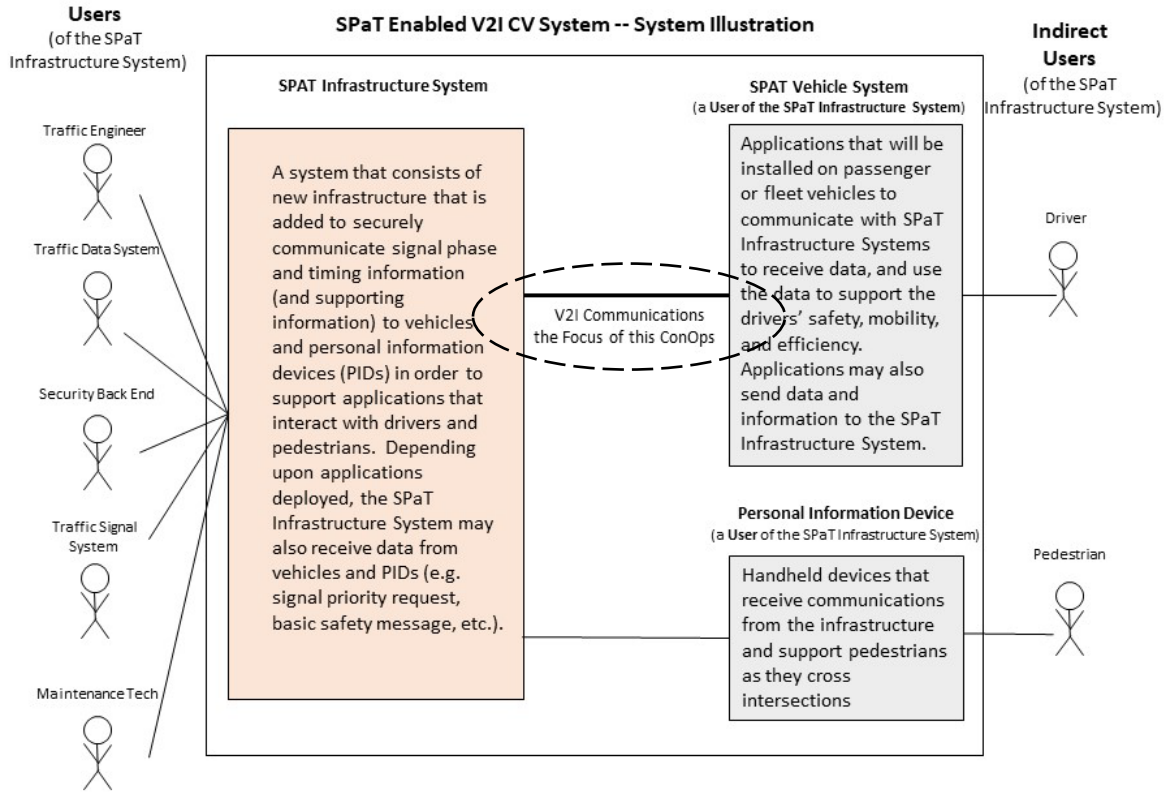

Figure 1 SPaT Enabled V2I Connected Vehicle System Source: SPaT Challenge Infrastructure System Model Concept of Operations

1.5 RLVW Application

SPaT is a supporting function that supports several V2I connected vehicle applications. This ConOps covers SPaT deployments that support RLVW. The RLVW application warns the driver when the signal timing and vehicle motion indicate a high risk of violating a red light. Additional applications utilize the SPaT V2I Interface but are not included in the current scope of the document.

2 Users

Direct users of the SPaT V2I Interface for RLVW include the following:

- **SPaT Vehicle System.** This includes vehicles equipped with the RLVW application. The SPaT Vehicle System directly interacts with the SPaT Infrastructure System using the SPaT V2I Interface for RLVW.

- **SPaT Infrastructure System.** This includes the Roadside Unit (RSU) and any roadside processes that obtain MAP data and SPaT data and optionally positioning correction data, format and encode it into standardized messages and transmit it wirelessly to the SPaT Vehicle System using the SPaT V2I Interface for RLVW.

3 User Needs

User needs for the SPaT V2I Interface for RLVW include what the SPaT Vehicle System needs from the SPaT Infrastructure System using the SPaT V2I Interface for RLVW as well as what the SPaT Infrastructure System needs from the SPaT Vehicle System using the interface. Many of the needs of one of these user systems have a mirrored need from the other system. For example, if the SPaT Vehicle System needs the SPaT Infrastructure System to provide a certain piece of information, then the SPaT Infrastructure System needs the SPaT Vehicle System to be able to receive that same piece of information. For simplicity, the needs are expressed as what the SPaT Vehicle System needs from the SPaT Infrastructure system without documenting the implied mirrored need.

3.1 Standard Communications Technology

A SPaT Vehicle System needs the SPaT Infrastructure System to utilize standard communications technology so that the SPaT Vehicle System will be able to receive and correctly interpret messages originating from any SPaT-enabled intersection.

Reference: SPaT Challenge Verification Document, 2.2.1 Infrastructure Requirements

Reference: CCIs, 2.1.5 Channel Utilization – DSRC Deployments

3.2 Standard Messages

A SPaT Vehicle System needs the SPaT Infrastructure System to utilize standard messages so that the SPaT Vehicle System will be able to receive and correctly interpret messages originating from any SPaT-enabled intersection.

Reference: SPaT Challenge Verification Document, 2.2.1 Infrastructure Requirements

3.3 Message Security

A SPaT Vehicle System needs the SPaT Infrastructure System to digitally sign messages in accordance with an agreed upon certificate policy utilizing a Security Credentials Management System that the SPaT Vehicle System trusts so that the SPaT Vehicle System will know the messages came from a trusted source and were not altered during transmission.

Reference: SPaT Challenge Verification Document, 2.2.1 Infrastructure Requirements

3.4 Common Time Reference

A SPaT Vehicle System needs the SPaT Infrastructure System to provide references to any fixed point in time using a common time reference so that the SPaT Vehicle System can properly interpret the time point.

Reference: SPaT Challenge Verification Document, 2.2.1 Infrastructure Requirements

Reference: CCIs, 2.1.1 Time accuracy and synchronization

3.5 Compact Messages

A SPaT Vehicle System needs the SPaT Infrastructure System to constrain message sizes so that the messages fit within the maximum message size supported by the communications stack.

Reference: CCIs, 2.1.3 Approach to node point latitude/longitude Representation

3.6 Message Revision

A SPaT Vehicle System needs the SPaT Infrastructure System to identify the message revision number of messages so that the SPaT Vehicle System can determine whether a received message is new and must be processed or is the same as a previous message and can be ignored.

Reference: SPaT Challenge Verification Document, 3.1 SPaT Message

Reference: SPaT Challenge Verification Document, 3.2 MAP Message

3.7 Message Time Stamp

For messages that contain absolute time reference, a SPaT Vehicle System needs the SPaT Infrastructure System to identify the time that the SPaT Infrastructure System created the message so that the SPaT Vehicle System can correctly resolve the time reference.

Reference: SPaT Challenge Verification Document, 3.1 SPaT Message

Reference: Test Procedure, 3.2.5 Message timestamps

3.8 Coverage

A SPaT Vehicle System needs the SPaT Infrastructure System to provide data far enough in advance of the intersection, with respect to both time and distance, so that the SPaT Vehicle System will be able to process the data by the time the applications require it.

Reference: SPaT Challenge Verification Document, 3.2.4 Mapping Requirements

Reference: Test Procedure 2.1.1 Node Points

Reference: CCIs, 2.2.1 SPaT message frequency of transmission

Reference: SPaT Data Needs, MAP Data Needs 1

3.9 Timeliness

A SPaT Vehicle System needs the SPaT Infrastructure System to provide data with low latency so that the SPaT Vehicle System can properly react to the dynamic situation at the intersection.

Reference: SPaT Challenge Verification Document, 3.1.4 Time Accuracy

Reference: Test Procedure, 2.2.6 Frequency

Reference: Test Procedure, 3.2.6 SPaT Frequency

Reference: CCIs, 2.2.1 SPaT message frequency of transmission

Reference: CCIs, 2.2.2 Signal State Frequency of Output from the signal controller

Reference: CCIs, 2.2.3 MAP message frequency of transmission

3.10 Quality Assurance

A SPaT Vehicle System needs the SPaT Infrastructure System to provide assurance that the information it is providing is correct without errors so that the SPaT Vehicle System can trust the information.

Reference: Enabling Connected Intersections, Section 2.C.7.

Reference: SPaT Data Needs, SPaT Data Needs 1

Reference: SPaT Data Needs, SPaT Data Needs 5

Reference: SPaT Data Needs, SPaT Data Needs 6

3.11 Unique Intersection Identification

A SPaT Vehicle System needs the SPaT Infrastructure System to uniquely identify the intersection so that the SPaT Vehicle System can associate the correct SPaT data with the intersection.

Reference: SPaT Challenge Verification Document, 3.1 SPaT Message

Reference: SPaT Challenge Verification Document, 3.2 MAP Message

Reference: CCIs, 2.1.9 Use of Intersection ID

3.12 Intersection Geometry

A SPaT Vehicle System needs the SPaT Infrastructure System to provide a MAP message containing the intersection lane geometry and location so that the SPaT Vehicle System can determine its own location in relation to the intersection lanes and stop bar.

Reference: SPaT Challenge Verification Document, 3.2 MAP Message

Reference: Test Procedure 2.1.1 Node Points

Reference: Test Procedure, 2.2.5 Lanes Verification

Reference: CCIs, 2.1.6 Configuration of turn lanes

Reference: SPaT Data Needs, MAP Data Needs 2

Reference: SPaT Data Needs, MAP Data Needs 3

3.13 Lane Attributes

A SPaT Vehicle System needs the SPaT Infrastructure System to provide information about the allowed use of the lanes at the intersection so that the SPaT Vehicle System can better determine which lane it is in and can provide the proper warnings, information and guidance to the driver.

3.14 Allowed Maneuvers

A SPaT Vehicle System needs the SPaT Infrastructure System to provide information about the maneuvers that are allowed at the intersection for the lane that the SPaT Vehicle System is in so that the SPaT Vehicle System can better determine its intended movement at the intersection and can provide the proper warnings, information and guidance to the driver.

Reference: SPaT Challenge Verification Document, 3.2.4.1 Ingress Lanes

Reference: Test Procedure, 2.2.5 Lanes Verification

Reference: CCIs, 2.1.6 Configuration of turn lanes

3.15 Connections Between Lanes

A SPaT Vehicle System needs the SPaT Infrastructure System to provide information about the connections between ingress lanes and egress lanes so that the SPaT Vehicle System can determine which part of the SPaT message applies to the movement the SPaT Vehicle System intends to make at the intersection.

Reference: SPaT Challenge Verification Document, 3.2.4.1 Ingress Lanes

Reference: Test Procedure, 2.2.1 SignalGroups

Reference: Test Procedure, 2.2.3 ConnectsTo (Connection)

Reference: Test Procedure, 2.2.4 Connection Maneuvers

Reference: Test Procedure, 3.2.4 SignalGroup

3.16 Position Correction

A SPaT Vehicle System sometimes needs the SPaT Infrastructure System to provide position correction data so that the SPaT Vehicle System can determine its position with enough accuracy to determine which lane it is in.

Reference: SPaT Challenge Verification Document, 2.2.1 Infrastructure Requirements

Reference: SPaT Challenge Verification Document, 6.3 Position Correction for Different Intersection Configurations

Reference: CCIs, 2.1.11 Inclusion of vehicle position correction data

Reference: CCIs, 2.2.4 RLVW vehicle position correction data exchange clarification

3.17 Enabled Lanes

A SPaT Vehicle System needs the SPaT Infrastructure System to identify which dynamic lanes are currently enabled so that the SPaT Vehicle System can determine the current allowable use of the lanes at the intersection.

3.18 Intersection Status

A SPaT Vehicle System needs the SPaT Infrastructure System to provide its overall status so that the SPaT Vehicle System can determine whether or not the intersection is in normal operation and can better interpret signal timing information.

Reference: SPaT Challenge Verification Document, Table 1: Required Data for SPaT Message Transmission for the RLVW Application

Reference: Enabling Connected Intersections, Section 2.C.7.

Reference: SPaT Data Needs, SPaT Data Needs 1

Reference: SPaT Data Needs, SPaT Data Needs 5

Reference: SPaT Data Needs, SPaT Data Needs 6

Reference: Test Procedure, 3.1.1 State

3.19 Movement State

A SPaT Vehicle System needs the SPaT Infrastructure System to provide the current state of the movement the SPaT Vehicle System intends to make at the intersection including whether a protected or permissive movement is allowed, a protected or permissive clearance (phase change interval) is in effect, the movement is required to stop then proceed or remain or a movement may proceed with caution with possible conflicting traffic so that the SPaT Vehicle System can provide the proper warnings, information or guidance to the driver.

Reference: SPaT Challenge Verification Document, 3.1 SPaT Message

Reference: Test Procedure, 3.1.1 State

3.20 Time Change Details

A SPaT Vehicle System needs the SPaT Infrastructure System to provide information about when the current signal interval (state) for the movement the SPaT Vehicle System intends to make at the intersection will change so that the SPaT Vehicle System can provide the proper warnings, information or guidance to the driver.

Reference: SPaT Challenge Verification Document, 3.1 SPaT Message

Reference: SPaT Data Needs, SPaT Data Needs 2

Reference: SPaT Data Needs, SPaT Data Needs 4

Reference: Test Procedure, 3.1.2 Min Time to Change

Reference: Test Procedure, 3.1.3 Min Time at Change

Reference: Test Procedure, 3.1.4 Max Time to Change

Reference: Test Procedure, 3.1.5 Max Time at Change

Reference: Test Procedure, 3.2.1 minEndTime

Reference: Test Procedure, 3.2.2 maxEndTime

Reference: Test Procedure, 3.2.3 LikelyTime

4 SPaT V2I Interface for RLVW Operational Scenario

This scenario illustrates how the applications within the scope of this ConOps use the SPaT V2I Interface for RLVW.

4.1 Initial Conditions

The following conditions must be in place before the scenario starts:

The SPaT Vehicle System:

- Is approaching the signalized intersection.
- Knows the intended maneuver the driver intends to make at the intersection (Left/Right/Through/U-turn).
- Continuously knows its current position, heading and speed.
- Is configured to receive SPAT and MAP messages, including supporting standard message security features.
- Is configured with the RLVW application enabled to support the driver.
- OPTIONAL - Is configured to receive position correction information and to apply it to its current position, as needed to support enabled applications.
- Is equipped with a clock that is synchronized with UTC Time.

The Traffic Signal System:

- Is operating normally, there are no preemption or priority currently in effect, and no failure mode flashing operation in effect.
- Has been configured and is sending data to the SPaT Infrastructure System to support a proper SPaT message.
    - Traffic signal vehicle phases and overlap phases are assigned to channels.
    - Channels are assigned to signal group IDs.
    - Overall signal status information is being provided to the SPaT Infrastructure System.
    - Movement states and timing for active signal groups are being provided to the SPaT Infrastructure System.

The SPaT Infrastructure System:

- Is configured and broadcasting a proper MAP message.
- Is configured and is receiving SPaT supporting data from the traffic signal system.
- Is configured and broadcasting a proper SPAT message.
- Supports standard message security features.

4.2 Sequence of events

The Scenario begins.

Map Message:

1. The SPaT Vehicle System receives the MAP message and validates the security credentials.
2. The SPaT Vehicle System checks the message revision number and determines it has never received this revision of the MAP message

   Variation - the SPaT Vehicle System determines it has already received this revision of the MAP message and skips step 3.
3. The SPaT Vehicle System decodes the MAP message and determines
   a. Intersection location.
   b. Ingress and egress center of lane geometry and location.
   c. Lane width, which combined with center of lane results in a lane polygon.
   d. Connections from ingress lanes to egress lanes via specific movements.
   e. The signal group IDs related to the connections.
4. OPTIONAL - The SPaT Vehicle System may receive position correction information and use it to more accurately determine its current position.
5. Based upon its current location and the lane geometry, the SPaT Vehicle System determines which lane it is in and its position with respect to the stop bar.
6. Based upon which lane it is in and the maneuver the driver intends to make at the intersection, the SPaT Vehicle System determines which connection to an egress lane in the map message represents the intended movement, and, knowing the connection, determines which signal group ID conveys information about the signal state and timing for that maneuver.
7. OPTIONAL – If the egress lanes have indicated a connection to lanes in an adjacent SPaT intersection, the SPaT Vehicle System determines the intersection ID for the next SPaT intersection it will encounter in order to facilitate communications in situations where multiple SPaT intersections are within range of the SPaT Vehicle System.

SPAT Message:

A. The SPaT Vehicle System receives the SPAT message and verifies the security credentials.
B. The SPaT Vehicle System checks the message revision number and determines it has never received this revision of the SPAT message

   Variation - the SPaT Vehicle System determines it has already received this revision of the SPAT message and skips steps C and D.
C. The SPaT Vehicle System decodes the SPAT message:

a. The SPaT Vehicle System determines that the overall intersection status does not indicate failure mode, failure flash, preemption or priority or other status which could call into question any movement state or timing information contained in the SPAT message.

   Variation - The SPaT Vehicle System determines from the overall intersection status that the SPaT message is not trustworthy. The scenario aborts and ends.

b. The SPaT Vehicle System determines from the overall intersection status that the traffic signal operation is traffic dependent, such that the SPAT message may not contain an exact end time of the intervals.

   Variation - The SPaT Vehicle System determines from the overall intersection status that the traffic signal operation is fixed time, such that the end time of the interval is predetermined and reflected in the minEndTime of the SPaT message for a signal group.

D. Based upon the relevant signal group ID that the SPaT Vehicle System determined from the MAP message, the SPaT Vehicle System determines

   a. What the current movement state is for the intended movement.

      Variation - If the SPAT message contains no information for the relevant signal group, the scenario aborts and ends.

   b. How much time is left for the current movement state. If the intersection status indicates that the traffic signal operation is traffic dependent, the SPaT Vehicle System determines for an end time for the movement state based on the SPaT message content for the minimum end time and maximum end time.

E. Based upon the position of the SPaT Vehicle System, the motion of the SPaT Vehicle System, the current movement state for the intended movement and the time the SPaT Vehicle System determines to be remaining for the movement state, the Spat Vehicle System determines that there is a high risk that the vehicle will enter the intersection on Red and provides a Red Light Violation warning or informational alert to the driver.

   Variation – The SPaT Vehicle System determines that there is low risk of the vehicle entering the intersection on Red and provides no warning to the driver.

F. The scenario repeats until the SPaT Vehicle System has entered the intersection.

4.3 End State

Once the SPaT Vehicle System determines that it has passed through the intersection, it stops processing MAP, SPaT or positioning correction messages from the intersection.

The Scenario ends.

5 Consideration of Additional Applications

This ConOps supports the RLVW application. Other applications that an IOO may want to implement at an intersection, and other applications that an OEM may want to implement within the vehicles, would entail additional needs. Other needs that may be considered for other applications that were intentionally omitted from this focused ConOps include:

- The need for state and timing information for pedestrian movements
- The need for speed limit information associated with the approaches to the intersection
- The need for information about when the next permitted state (green) will come up for the movement
- The need for information about queues at the intersection
- The need for an indication of detection of pedestrians and bicycles in the crosswalk

6 Operational Concept for SPaT V2I Interface for RLVW

[This section will describe items such as minEndTime and maxEndTime during rest in green, time mark rather than countdown, etc., that have been identified in other documents as needing clarification.]

7 Referenced Documents

SAE J2735 – Surface Vehicle Standard J2735, MAR2016, Dedicated Short Range Communications (DSRC) Message Set Dictionary, Society of Automotive Engineers International

SPaT Challenge Verification Document – SPaT Challenge Verification Document, Version 1.2, Crash Avoidance Metrics Partners LLC (CAMP), October 30, 2017

Test Procedure - Test Procedure for Verifying SPaT and MAP Messages, Connected Signalized Intersections, Version 1.2, Crash Avoidance Metrics Partners LLC (CAMP), September 18, 2019

CCIs - Cooperative Automated Transportation, Clarifications for Consistent Implementations (CCIs) To Ensure National Interoperability, Connected Signalized Intersections, DRAFT Version 1.9.4, May 2019

Enabling Connected Intersections - Enabling Connected Intersections, Connected Intersection Communications with Production Vehicles, February 2020

SPaT Data Needs - Connected Signalized Intersections, SPaT Data Needs, Draft Version 6 – Updated following Dec 9, 2019 Discussion

SPaT Inconsistency – SPaT Inconsistency in Actuated Signalized Intersections [No reference information is provided in the document]

Additional Ambiguities - Additional ambiguities in Standard (J2735) [No reference information is provided in the document]

SPaT Challenge Infrastructure System Model Concept of Operations - SPaT Challenge Infrastructure System Model Concept of Operations, Draft Version 1.6, March 2018

SPaT Challenge Infrastructure System Model Requirements - SPaT Challenge Infrastructure System Model Requirements, Draft Version 1.1, March 2018

SRS - SPaT V2I Interface for Red Light Violation Warning, System Requirements Specification, Version 20200409, Minnesota Department of Transportation, April, 2020