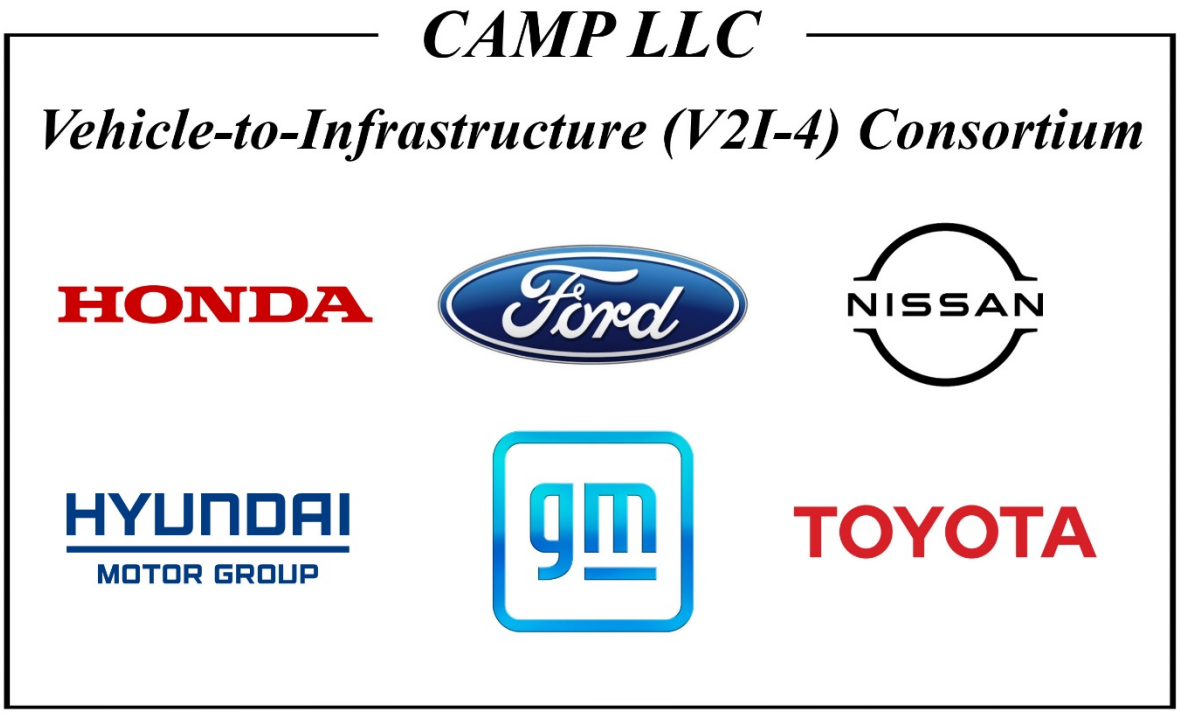

Red Light Violation Warning (RLVW) Application Vehicle System

High-level System Requirements

Version 1.10

1/12/2021

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1. Introduction

1.1 Background

This document presents High-level Requirements for the Red Light Violation Warning (RLVW) application. This document builds on the RLVW Application Vehicle System Concept of Operations with traceability to the system needs in that document.

The intent of the RLVW application is to influence drivers approaching the intersection that are either unintentionally not stopping at red lights or would not pass the intersection before the red interval begins, both of which could lead to conflicts with cross-traffic and pedestrians.

This document describes the proposed RLVW Application Vehicle System High-level Requirements.

The intent of the RLVW application is to influence drivers approaching the intersection that are either unintentionally not stopping at red lights or would not pass the intersection before the red interval begins, both of which could lead to conflicts with cross-traffic and pedestrians.

1.2 Purpose

The intent of this document is to articulate the RLVW High-level Requirements that map to specific operational concepts for RLVW in the Concept of Operations. Once finalized, these High-level Requirements will be used as a basis for generating more detailed functional requirements. These High-level Requirements describe "what" the proposed system components would need to do but not "how" they will do them. To that end, the following flow diagrams in Figure 1 and Figure 2 illustrate the key decisions of the RLVW application and introduce the concept of mandatory information describing the interval end time that is needed.

The primary audience for these High-level Requirements are the automotive Original Equipment Manufacturers (OEMs) and Infrastructure Owners and Operators (IOOs) that will develop, implement, and operate the connected vehicle-infrastructure system needed to implement the RLVW application. These High-level Requirements will help stakeholders envision the proposed system concept and begin planning, designing, and executing portions of the concept.

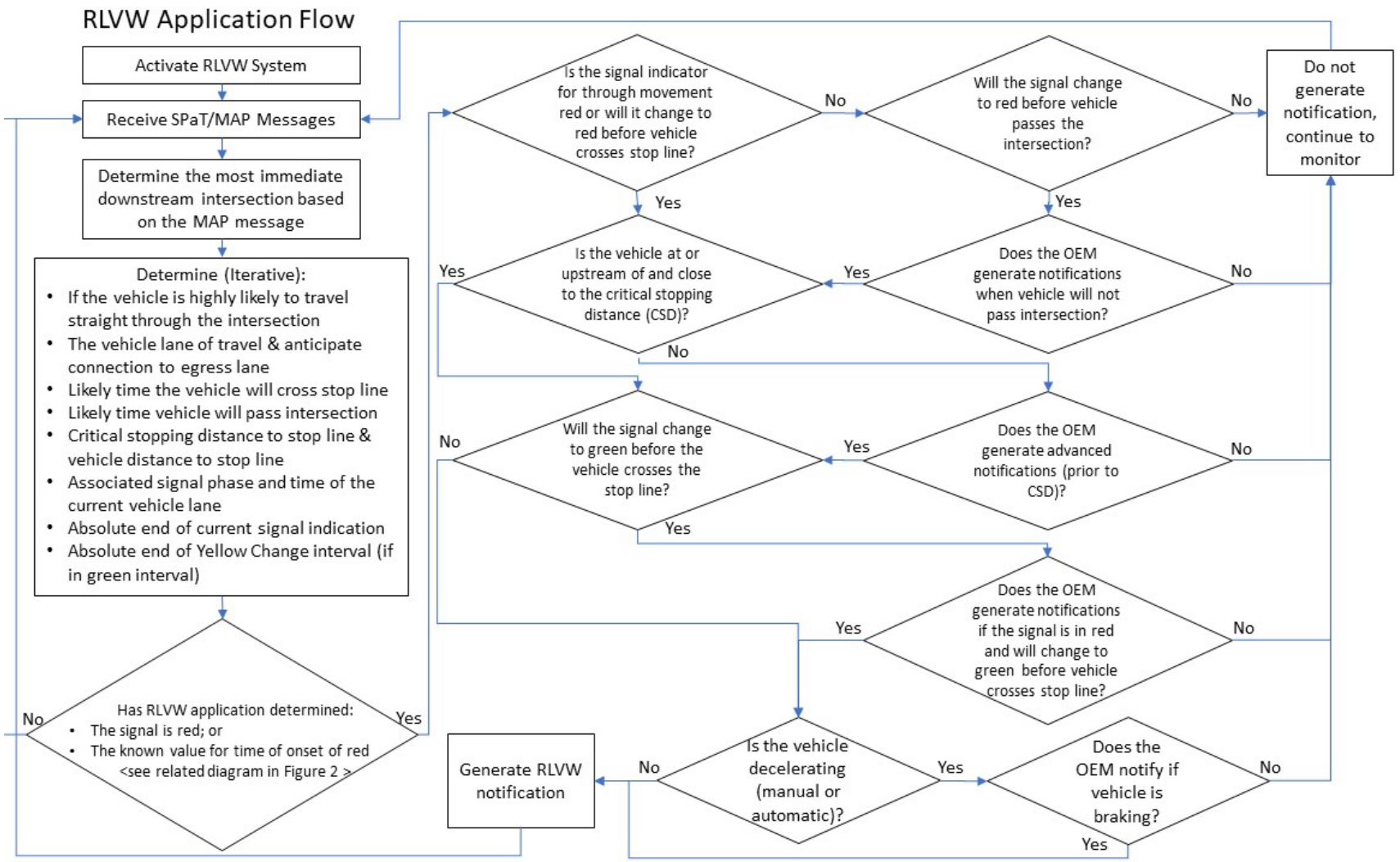


Figure 1: RLVW Application Flow Diagram

Scenarios resulting in the RLVW having the information to determine:

- Time of onset of red indication; or
- That the signal is currently in red indication

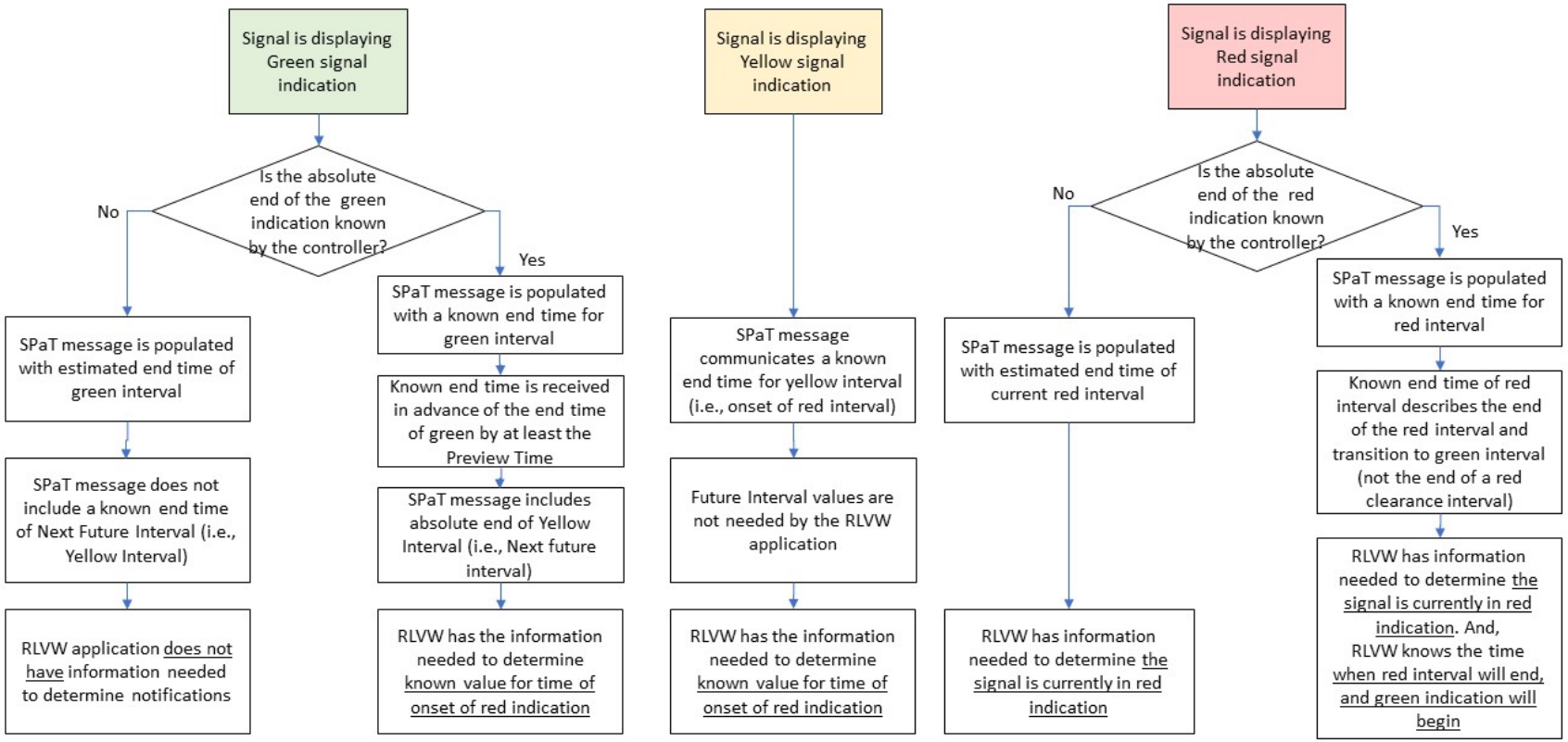


Figure 2: Scenarios Resulting in the RLVW Application Having the Information to Determine the Time of Onset of Red Indication or that the Signal is Currently in Red Indication

1.3 Document Overview

The proposed high-level requirements described herein document the RLVW application. The organization of this document following this section are as follows:

- Section 2 describes **High-level Vehicle Requirements**, including Data Processing and Determining Actions, Human Machine Interface (HMI), Vehicle Communications, Braking Controls, Positioning, and Security Credential Processing
- Section 3 describes **High-level Infrastructure Requirements**, including the Information Creation and Processing, and Information Broadcast.
- Section 4 provides a **Glossary of Terms and Key Definitions**.
- The Appendix provides **calculations describing the need for a period of time preceding the interval change when a known true value for the interval end time is needed**.

The diagram in Figure 3 below illustrates the functions representing the groups of requirements presented in Section 2 and Section 3 for the RLVW-equipped vehicle and infrastructure, respectively. In most situations, the "data processing and determining actions" function within the RLVW-equipped vehicle will be considered the RLVW application, as marked in Figure 3, while the RLVW application relies on the HMI, vehicle communications, braking controls, positioning, and security credential processing that exist on the vehicle. The requirements described in the following sections are written to describe this arrangement.

Additionally, although requirements in the sections below are grouped to support the review and discussion process, the grouping of requirements does not imply any chronological order of events or functions and only states "what" must be performed. Design decisions will determine what subsystems perform what functions at what time and in what order.

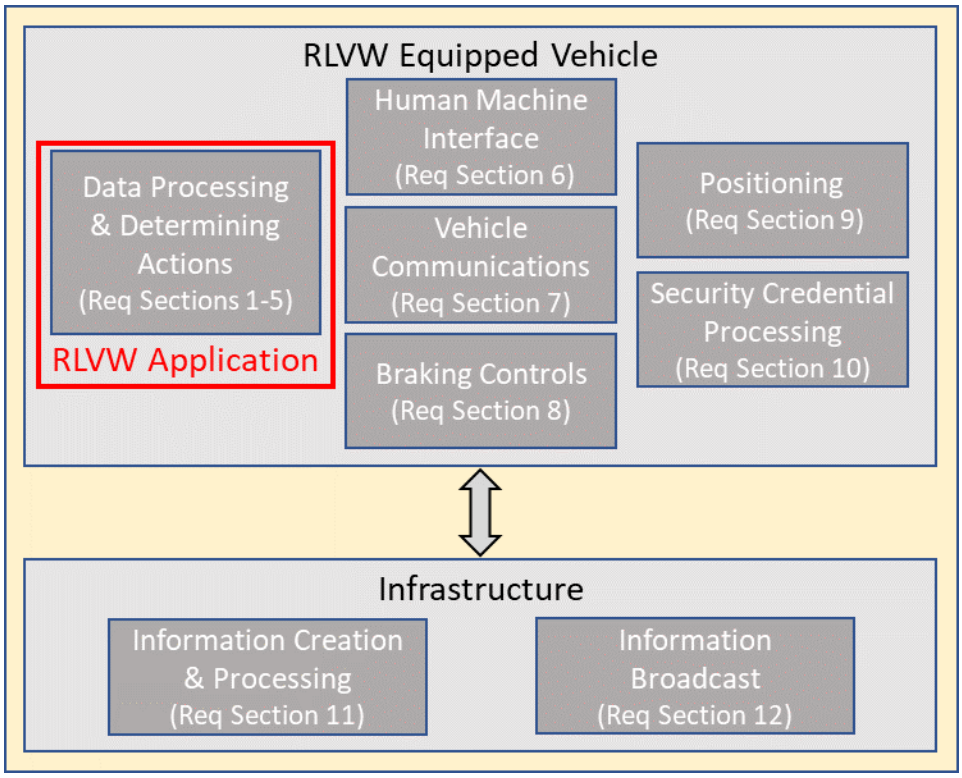


Figure 3: Diagram of RLVW-equipped Vehicle and Infrastructure Function Groups for Requirement Sections

2. High-level Vehicle Requirements

The High-level Vehicle Requirements in Table 1 describe requirements for the RLVW application on RLVW-equipped vehicles (i.e., RLVW vehicles) to receive and use information from the infrastructure provided via infrastructure-to-vehicle (I2V) communications (also sometimes broadly referred to as vehicle-to-infrastructure [V2I] communications). Table 1 links each High-level Vehicle Requirement to a System Need presented in the RLVW Application Vehicle System Concept of Operations.

The grouping and ordering of requirements are intended to organize requirements for the review process and later use of the requirements. There is no chronological ordering of activities or assignment of how the requirement is performed intended by this structure. The design of the RLVW would determine what systems perform what functions and the time dependencies of these.

All requirements that reference an industry standard (e.g., SAE J2735 standard or other) refer to the latest version of the standard unless otherwise noted.

Table 1: High-level Vehicle System Requirements

High-level Vehicle System Requirement	ConOps System Need #
RLVW Application Requirements	
1. General Operations	
1.1 RLVW vehicles shall activate the RLVW application upon vehicle start-up without driver interaction.	51
1.2 RLVW vehicles shall activate the RLVW application only if the driver/owner of the vehicle has not opted out of the application (per OEM-specific designs).	52
1.3 The RLVW application shall include an option for the driver/owner of the vehicle to opt out of the RLVW application via the HMI (per OEM-specific designs).	52
1.4 The RLVW application <u>may</u> include an option for the driver to adjust parameters for issuing notifications based on their comfort level.	53
1.5 The RLVW application <u>may</u> provide indications to the HMI for the driver about operational status of the RLVW application, per OEM-specific designs.	54
2. Receive and Process Data from other Vehicle Components *Summary: The requirements in this subsection describe what the RLVW application must do to receive messages or data from other Vehicle Components and to process the messages to make the data available for the calculations described in requirements in subsection 3 (i.e., requirements starting with the number 3).*	
2.1 The RLVW application shall receive notifications from the Vehicle Communications of received valid Wireless Access in Vehicular Environments (WAVE) Service Advertisements (WSA), regardless of whether there are additional valid certificates (e.g., for SPaT and MAP messages).	22, 57
2.1.1 If a WSA accompanying a SPaT message conveys that the SPaT message is not valid, RLVW application shall not process or use the SPaT message content.	87
2.1.2 If a WSA accompanying a MAP message conveys that the MAP message is not valid, RLVW application shall not process or use the MAP message content.	87

High-level Vehicle System Requirement	ConOps System Need #
2.1.3 If a WSA accompanying an RTCM message conveys that the RTCM message is not valid, RLVW application shall not process or use the data contained in the RTCM message.	87
2.2 The RLVW application shall receive and process SPaT messages from Vehicle Communications.	1, 55
2.2.1 The RLVW application shall only receive SPaT messages that Security Credential Processing has determined to have been signed with valid certificates.	22, 57
2.2.2 The RLVW application shall process the SPaT message to determine the status of the intersection signal controller. Operational decisions based on the intersection status are OEM-specific.	4, 71
2.2.3 The RLVW application shall process the SPaT message to determine the current signal indication (i.e., green, yellow, red) of signal control groups.	2
2.2.4 The RLVW application shall process the SPaT message to determine the time mark of the absolute end time of the current signal indication for each signal group.	7, 71
2.2.5 The RLVW application shall process the SPaT message to determine the time mark of the end of the next future interval for each signal group. For example, during a green interval, RLVW will process the SPaT message to determine the time mark of the end of the yellow interval, and during a yellow interval, RLVW will process the SPaT message to determine the time mark of the end of the red interval.	5
2.2.6 The RLVW application shall process SPaT messages as soon as received within 100 milliseconds.	1, 55
2.3 The RLVW application shall receive and process MAP messages from the Vehicle Communications.	8, 55
2.3.1 The RLVW application shall only receive MAP messages that Security Credential Processing has determined have been signed with valid certificates.	57
2.3.2 The RLVW application shall process available geographic location data of lane node points from the MAP message.	63
2.3.3 The RLVW application shall process available elevation data of node points.	13
2.3.4 The RLVW application shall process node points to determine which are assigned to ingress lanes and which are assigned to egress lanes.	55
2.3.5 The RLVW application shall process MAP messages to determine lane width values.	55, 67
2.3.5.1 The RLVW application shall determine lane widths for individual lanes when the MAP message describes lane width variations from the reference lane width (defined as a delta value in the MAP message).	67
2.3.6 The RLVW application shall process MAP messages to extract details of signal groups that correlate to the connections between lanes, as defined in the MAP message.	65
2.3.7 The RLVW application shall receive and process MAP messages as soon as received, within 100 milliseconds.	8
2.3.8 The RLVW application shall process MAP messages to extract posted speed limits.	62

High-level Vehicle System Requirement	ConOps System Need #
2.3.9 The RLVW application shall be able to process MAP messages that include computed lanes.	62
2.3.10 The RLVW application shall be able to process MAP messages that include revocable lanes.	62
2.4 The RLVW application shall receive and process information available from Vehicle Positioning about current vehicle position.	60, 61
2.4.1 The RLVW application shall receive and process vehicle position information at least as frequent as 10 times per second.	60, 61
2.5 The RLVW application shall confirm that the SPaT and MAP messages describe a common intersection (using Road Regulator ID and Intersection ID).	58
2.5.1 The RLVW application shall process available Road Regulator ID and Intersection ID data from the SPaT message that identify the intersection.	58
2.5.2 The RLVW application shall process available Road Regulator ID and Intersection ID data from the MAP message that identify the intersection.	58
2.5.3 The RLVW application shall use the MAP message of the most immediate downstream intersection to find the matching SPaT message by comparing both Road Regulator ID and Intersection ID data of MAP and SPaT messages.	58
2.6 The RLVW application shall receive and process vehicle speed from other vehicle systems.	60
2.7 The RLVW application shall receive and process braking control data from vehicle Braking Controls.	60, 82
2.7.1 The RLVW application shall receive and process data describing brake application.	60, 82
2.7.2 The RLVW application shall receive and process data describing vehicle deceleration rate.	60
3. Perform Calculations *Summary: The requirements in this subsection describe what the RLVW application must do to perform the calculations needed to generate notifications in Subsection 4 (i.e., requirements starting with number 4). All the data required to perform these requirements should have been received and processed in Subsection 2.*	
3.1 The RLVW application shall determine the most immediate downstream connected signalized intersection even when receiving SAE J2735 messages from multiple intersections.	56
3.1.1 The RLVW application shall determine and only consider data describing the most immediate connected signalized intersection that the vehicle is approaching downstream along the path of travel even when receiving MAP messages from multiple intersections.	56
3.2 The RLVW application shall perform calculations to determine the lane of travel using data processed from the MAP message and the vehicle position.	63
3.3 The RLVW application shall determine if the vehicle's anticipated movement through the intersection will be a straight maneuver.	64
3.3.1 The RLVW application shall process available data from the MAP message regarding connections to egress lanes at the intersection and the vehicle's lane of	64

High-level Vehicle System Requirement	ConOps System Need #
travel in order to determine whether the vehicle's anticipated movement is straight.	
3.3.2 The RLVW application shall determine the connection (as defined in the MAP message) that is associated with the anticipated movement.	64
3.3.3 The RLVW application shall continuously determine lane of travel to reassess the anticipated movement.	83
3.3.4 The RLVW application shall perform limited functions, per OEM-specific designs, if the vehicle's anticipated movement is not straight.	85
3.4 The RLVW application shall calculate vehicle position parameters needed to determine notifications.	66
3.4.1 The RLVW application shall determine the absolute location of the stop line of the lane of travel.	66
3.4.1.1 The RLVW application shall rely upon the first node of the ingress lane of travel representing the upstream edge of the stop line of the lane in the MAP message.	66
3.4.2 The RLVW application shall determine the time that the vehicle is expected to cross the stop line, based on current vehicle speed and trajectory.	75
3.4.3 If the RLVW application includes the issuance of notifications to vehicles not likely to pass the intersection before the red indication, the RLVW application shall determine the absolute location of the downstream edge of the intersection. Note: downstream intersection edge may be determined using the position of the first egress node of the egress lane or by OEM-specific designs.	67
3.4.4 If the RLVW application includes the issuance of notifications to vehicles not likely to pass the intersection before the red indication, the RLVW application shall determine the time that the vehicle is expected to clear the downstream edge of the intersection.	77
3.5 The RLVW application shall determine the signal group that provides traffic control for the movement between the lane of travel and the connecting lane that the vehicle is expected to use to egress the intersection.	65
3.5.1 The RLVW application shall use the extracted signal group data from the MAP message (see Requirement 2.3.6) and the determined connection (see Requirement 3.3.2) to determine the signal group that provides control for the connection that describes the anticipated movement through the intersection.	65
3.6 The RLVW application shall determine the current signal movement state of traffic control for the anticipated movement.	70, 71
3.6.1 The RLVW application shall use the determined signal group for the lane of travel and the movement state for each signal group to determine if the current signal indication is green, yellow, or red for the lane of travel.	70
3.7 The RLVW application shall determine the absolute end time of the current movement state of traffic control for the lane of travel.	70, 71
3.7.1 The RLVW application shall use the signal state and time marks (as processed from the SPaT message) to determine the absolute end time of the current signal indication.	71

High-level Vehicle System Requirement	ConOps System Need #
3.7.2 The RLVW application shall determine if the time marks representing end time of the current signal indication are true and known values or estimated values, and it shall make operational decisions based on OEM-specific designs. (i.e., is the time mark the time the signal indication will change or is the intersection resting at that time value?)	74
3.8 The RLVW application shall determine the absolute time of the onset of the red signal indication for the anticipated movement.	73
3.8.1 If the RLVW application determines that the current signal indication is yellow, the RLVW application shall determine the absolute time of onset of the red signal indication as the absolute end time of the current signal indication.	71, 72, 73
3.8.2 If the RLVW application determines that the current signal indication is green, the RLVW application shall determine the absolute time of the onset of the red signal indication as the absolute end time of the yellow indication (next future interval) if the next future interval data is available.	71, 72, 73
3.9 The RLVW application shall calculate the grade of the approach to the intersection.	69
3.9.1 The RLVW application shall calculate grade using the elevation data of ingress lane node points from the MAP message for the lane of travel.	69
3.10 The RLVW application shall calculate the critical stopping distance/time of the vehicle.	75, 80
3.10.1 The RLVW application shall use current speed, grade, and vehicle parameters to calculate the earliest time mark (absolute time) that the vehicle could stop safely, per OEM-specific designs.	75, 80
3.11 The RLVW application shall continuously update calculations used for generating notifications based on newly received data and messages, as appropriate and based on OEM-specific designs.	82, 83
4. Generate Notifications *Summary: The requirements in this subsection describe what the RLVW application must do to generate notifications. When generating notifications, the RLVW application will use the result of the calculations performed in subsection 3 above.*	
4.1 The RLVW application may generate OEM-specific notifications to be delivered by the HMI to the driver when connected intersections are detected, per OEM-specific designs.	59
4.2 The RLVW application shall generate notifications, as appropriate, when the vehicle is approaching a signal group for the lane of travel that has a red signal indication, per OEM design.	79, 80
4.2.1 Notifications generated for vehicles approaching red signal indications shall include notifications to be delivered to the driver by the HMI.	78. 79
4.2.1.1 The RLVW application shall generate notification(s) early enough to allow the HMI to deliver notices to drivers prior to the critical stopping distance to the stop line.	80
4.2.2 Notifications generated for vehicles approaching red signal indications may include messages to the Vehicle Braking Control to activate braking assist or automated braking.	84

High-level Vehicle System Requirement	ConOps System Need #
4.2.2.1 The RLVW application shall generate notification(s) early enough to allow the Vehicle Braking Controls to perform braking activities prior to the critical stopping distance to the stop line.	80
4.2.3 When determining notifications for vehicles approaching a red signal indication, the RLVW application shall consider the end time of the red interval, vehicle time/distance to stop line, vehicle speed, and vehicle deceleration status. Note that the decision of whether to notify drivers at (or near) the critical stopping distance during a red signal indication, even if the indication change to green will occur before vehicle passes the stop line, is an OEM-specific design decision.	79
4.2.4 The RLVW application shall monitor the status of vehicle braking based on OEM-specific designs to determine when to terminate or not issue notifications during the red signal indication.	82
4.3 The RLVW application shall generate notifications when the vehicle is approaching a signal group for the lane of travel that is not in red interval.	75, 76, 77, 78
4.3.1 The RLVW application shall generate notifications when the vehicle is not likely to pass the stop line before the onset of the red interval.	75, 76
4.3.1.1 Notifications generated for vehicles not likely to pass the stop line shall include notifications to be delivered to the driver by the HMI.	76
4.3.1.1.1 The RLVW application shall generate notification(s) early enough to allow the HMI to deliver notices to drivers prior to the critical stopping distance to the stop line.	80
4.3.1.1.2 If consideration of the critical stopping distance, the vehicle speed, and the time to a red signal indication creates a situation where notifications to drivers must be delivered during the green signal indication, the RLVW application may generate notifications during the green signal indication, per OEM-specific designs.	80
4.3.1.2 Notifications generated for vehicles not likely to pass the stop line may include messages to the Vehicle Braking Control to activate braking assist or automated braking, per OEM design.	84
4.3.1.2.1 The RLVW application shall generate notification(s) early enough to allow the Vehicle Braking Controls to perform braking activities prior to the critical stopping distance to the stop line.	80
4.3.1.3 The RLVW application shall consider the absolute time of onset of the red interval and the calculated time the vehicle will cross the stop line according to OEM-specific designs, when generating notifications.	75
4.3.1.4 The RLVW application shall monitor the status of vehicle braking based on OEM-specific designs to determine when to terminate or not issue notifications during non-red intervals.	82
4.3.2 If the RLVW application includes the issuance of notifications to vehicles not likely to pass the intersection before the red indication, the RLVW application shall generate notifications when the vehicle is not likely to pass the intersection before the signal indication changes to red.	77, 78
4.3.2.1 Notifications generated for vehicles not likely to pass the intersection shall include notifications to be delivered to the driver by the HMI.	78

High-level Vehicle System Requirement	ConOps System Need #
4.3.2.1.1 The RLVW application shall generate notification(s) early enough to allow the HMI to deliver notices to drivers prior to the critical stopping distance to the stop line.	80
4.3.2.1.2 If consideration of the critical stopping distance, the vehicle speed, and the absolute onset time of the red signal indication creates a situation where notifications to drivers must be delivered during the green signal indication, the RLVW application may generate notifications during the green signal indication, per OEM-specific designs.	80
4.3.2.2 Notifications generated for vehicles not likely to pass the intersection may include messages to the Vehicle Braking Control to activate braking assist or automated braking, per OEM-specific designs.	80
4.3.2.2.1 The RLVW application shall generate notification(s) early enough to allow the Vehicle Braking Controls to perform braking activities prior to the critical stopping distance to the stop line.	80
4.3.2.3 The RLVW application shall consider the absolute time of onset of the red interval and the calculated time the vehicle will pass the intersection according to OEM-specific designs when generating notifications.	77
4.3.2.4 The RLVW application shall monitor the status of vehicle braking based on OEM-specific designs to determine when to terminate or not issue notifications during non-red signal indications.	82
4.3.3 The RLVW application may generate informational notifications when the change in signal indication from green to yellow is imminent.	76, 78, 80
4.3.3.1 The RLVW application shall consider vehicle speed, distance from the stop line, and time to a yellow signal indication against OEM-specific designs to generate notifications of imminent change in signal indication.	76, 78, 80
4.3.4 The RLVW application may generate informational notifications when the change in signal indication from yellow to red is imminent.	86
4.3.4.1 The RLVW application shall consider vehicle speed, distance from the stop line, and time to red signal indication against OEM-specific designs to generate notifications of imminent change in signal indication.	87
4.4 The RLVW application shall refrain from generating notifications for drivers who will pass the intersection before signal indication changes to red.	81
5. Deliver Notifications to the HMI *Summary: The requirements in this subsection describe what the RLVW application must do to deliver the notifications generated in Subsection 4 to the HMI. The HMI will then deliver the notifications to the drivers.*	
5.1 The RLVW application shall deliver notifications generated by the RLVW application to the HMI.	59, 76, 78, 80
5.1.1 The RLVW application may deliver OEM-specific notifications to the HMI for the driver when connected intersections are detected (including situations when there is no potential for violations), per OEM-specific designs.	59
5.1.2 The RLVW application shall deliver notifications to the HMI for drivers who are not likely to pass the stop line before the onset of the red signal indication.	76

High-level Vehicle System Requirement	ConOps System Need #
5.1.3 The RLVW application may deliver notifications to the HMI for drivers who are not likely to pass the intersection before the onset of the red signal indication, based on OEM-specific designs for when to notify drivers.	78
5.1.4 The RLVW application shall deliver all RLVW notifications to the HMI while the vehicle has time/distance to stop safely before the stop line (i.e., are upstream of the CSD to the stop line).	80
5.1.5 The RLVW application shall terminate any notifications previously delivered to the HMI when the RLVW application determines drivers will clear the intersection before the signal indication changes to red, based on OEM-specific designs.	81, 82
6. Human Machine Interface Requirements *Summary: Although it is not the focus of these requirements, some high-level requirements are included here to describe the role of the HMI in context to the RLVW application.*	
6.1 RLVW vehicles shall issue notifications to drivers. This would be done by the HMI per RLVW application recommendations, based on OEM-specific designs for when and how to notify drivers.	76, 78, 80
6.2 RLVW vehicles shall terminate RLVW notifications when appropriate conditions exist. This would be done by the HMI per RLVW application recommendations, based on OEM-specific designs for when and how to notify drivers.	81, 82
7. Vehicle Communications Requirements *Summary: Although it is not the focus of these requirements, some high-level requirements are included here to describe the role of the Vehicle Communications in context to the RLVW application.*	
7.1 Connected Vehicles shall have the communications capability to receive digitally signed messages with security certificates from the infrastructure and make these messages available to the Vehicle Security Processing.	22, 55
7.2 Connected Vehicles shall have the communications capability to receive digitally signed Signal Phase and Timing (SPaT) messages that conform to the SAE J2735 standard at a frequency of 10 Hz.	1, 55
7.3 Connected Vehicles shall have the communications capability to receive digitally signed MAP messages that conform to the SAE J2735 standard at a frequency of 1 Hz.	8, 55
7.4 Connected Vehicles shall have the communications capability to receive digitally signed Radio Technical Commission for Maritime Services (RTCM) messages that conform to the SAE J2735 standard at the following frequencies: • 5 Hz for message type 1001 – GPS L1 Observations • 2 Hz for message type 1005 – antenna reference point coordinates	21, 55
8. Braking Controls Requirements *Summary: Although it is not the focus of these requirements, some high-level requirements are included here to describe the role of the Braking Controls in context to the RLVW application.*	
8.1 RLVW vehicle braking controls shall receive and process messages from the RLVW application describing braking assist requests, per OEM-specific designs.	84

High-level Vehicle System Requirement	ConOps System Need #
8.2 RLVW vehicles shall provide data to the RLVW application about whether the driver is currently applying the brakes.	26
8.3 RLVW vehicles shall provide data to the RLVW application describing the current deceleration of the vehicle.	60
9. Security Credential Processing Requirements *Summary: Although it is not the focus of these requirements, some high-level requirements are included here to describe the role of the Security Credential Processing in context to the RLVW application.*	
9.1 RLVW vehicles shall process messages received by the Vehicle Communications to ensure that only messages signed with valid certificates are sent to the RLVW application.	22, 57
9.1.1 RLVW vehicles shall send notifications to the RLVW Application each time a connected intersection Wireless Access in Vehicular Environments (WAVE) Service Advertisement (WSA) broadcast is received with a valid certificate, regardless of whether there are additional valid certificates (e.g., for SPaT and MAP messages).	57
9.1.2 RLVW vehicles shall only send SPaT and MAP messages to the RLVW application if the messages are signed with valid certificates.	57
9.2 RLVW vehicles shall process security certificates against the Certificate Revocation List and disregard messages signed with invalid or revoked certificates, according to OEM-specific designs.	22, 57
10. Positioning Requirements *Summary: Although it is not the focus of these requirements, some high-level requirements are included here to describe the role of the Vehicle Positioning in context to the RLVW application.*	
10.1 RLVW vehicles shall determine the position of the vehicle.	60
10.2 RLVW vehicles may apply position correction data received by vehicle communications to improve accuracy of vehicle position determinations.	61
10.2.1 RLVW vehicles shall process data from Radio Technical Commission for Maritime Services (RTCM) messages that are received from vehicle communications.	21, 55, 61
10.3 RLVW vehicles shall provide data to the RLVW application about current vehicle position.	60

3. High-level Infrastructure Requirements

High-level Infrastructure Requirements to support the RLVW application are presented in Table 2 below. Additionally, each High-level Infrastructure Requirement in Table 2 is linked to a System Need presented in the RLVW Application Vehicle System Concept of Operations.

All requirements that reference an industry standard (e.g., SAE J2735 standard or other) refer to the latest version of the standard unless otherwise noted.

Table 2 High-level Infrastructure System Requirements

High-level Infrastructure System Requirement	ConOps System Need #
11. Information Creation and Processing Requirements	
11.1 The infrastructure shall create SPaT messages that conform to the SAE J2735 standard.	1
11.1.1 The infrastructure shall include a Road Regulator ID in each SPaT message.	3
11.1.2 The infrastructure shall include an Intersection ID in each SPaT message.	3
11.1.2.1 The combination of Road Regulator ID and Intersection ID in the SPaT message shall be unique within North America to the intersection described by the SPaT message.	3
11.1.2.2 The combination of Road Regulator ID and Intersection ID contained in the SPaT message shall match the combination of these fields in the MAP message for the same intersection.	3
11.1.3 The infrastructure shall include a 'Status' element in each SPaT message that accurately reflects the current operational status of the intersection (e.g., "Fixed Time Operation" or "Traffic Dependent Operations").	4
11.1.3.1 The infrastructure shall communicate the intersection status as 'manual control enabled' when timing is per programmed values but operators at the cabinet can manually request early termination of intervals.	4
11.1.3.2 The infrastructure shall communicate the intersection status as 'stop time is activated' when the controller stop timing is activated, causing a temporary stop in the signal timing and all intervals remain as they are until the status changes.	4
11.1.3.3 The infrastructure shall communicate the intersection status as 'failure flash' when the signal is in a flash mode invoked outside the signal controller (e.g., during any hardware failures or police panel).	4
11.1.3.4 The infrastructure shall communicate the intersection status as 'preempt is active' when the signal control is preempted (e.g., emergency vehicle preemption).	4
11.1.3.5 The infrastructure shall communicate the intersection status as 'signal priority is active' when the signal control is delivering priority to one or more movements (e.g., during transit vehicle priority).	4
11.1.3.6 The infrastructure shall communicate the intersection status as 'fixed time operation' when signal schedules are based on time only.	4
11.1.3.7 The infrastructure shall communicate the intersection status as 'traffic dependent operation' when signal operation is impacted by traffic inputs.	4

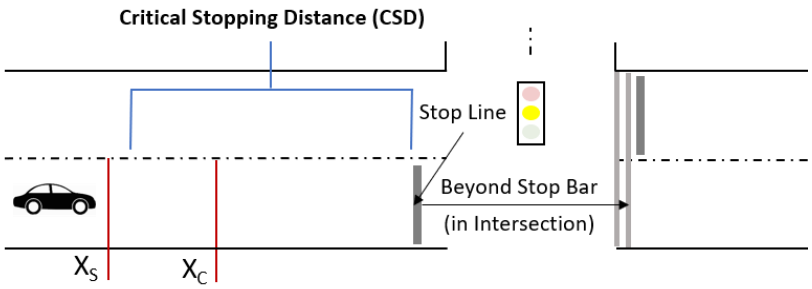
High-level Infrastructure System Requirement	ConOps System Need #
11.1.3.8 The infrastructure shall communicate the intersection status as 'standby operation' when the signal is in a signal flash condition invoked by the signal controller (e.g., time-of-day flash, start-up, preemption flash).	4
11.1.3.9 The infrastructure shall communicate the intersection status as 'failure mode' when the controller has a problem or failure in operation.	4
11.1.3.10 The infrastructure shall communicate the intersection status as 'off' when the signal controller is not providing valid data.	4
11.1.4 The infrastructure shall include data in the SPaT message that identifies the current interval/state of each signal group at the intersection (e.g., red, green, yellow, yellow flash, etc.).	2
11.1.4.1 The infrastructure shall include information describing the absolute end time of the current interval for each signal group in each SPaT message.	6
11.1.4.2 If the end time of the current interval for any signal group is estimated (i.e., not a known true value) then the infrastructure shall provide a known true value for the end time of the current interval in advance of the interval change, as outlined in the Appendix. The table in the Appendix to this document identifies the advanced time (i.e., preview time) before the interval change that the infrastructure is required to communicate the known true value for end of interval (for example, at 50 mph notice of the known interval end time is needed at least 2 seconds before interval end). See the Appendix for a matrix describing details.	7
11.1.4.3 During red clearance intervals, the infrastructure shall clearly identify the end time that is reported as either the end of the red clearance interval or the end of the overall red interval.	7
11.1.4.4 The data provided by the infrastructure SPaT messages shall include the data necessary for the RLVW application to determine whether the time mark describing the end of the current interval is a true and known value or an estimate.	6, 73
11.1.5 For signal groups in green interval, the infrastructure shall include absolute end time of the yellow change interval that follows the green interval (i.e., time of next future interval) in each SPaT message.	5
11.2 The infrastructure shall create MAP messages that conform to the SAE J2735 standard with data that represents the intersection geometry and relation to signal phases.	8
11.2.1 The infrastructure shall include a Road Regulator ID with each MAP message.	17
11.2.2 The infrastructure shall include Intersection ID with each MAP message.	17
11.2.2.1 The combination of Road Regulator ID and Intersection ID contained in the MAP message shall be unique to the intersection described by the MAP message.	17
11.2.2.2 The combination of Road Regulator ID and Intersection ID contained in the MAP message shall match the combination of these fields in the SPaT message for the same intersection.	17
11.2.3 The infrastructure shall include a reference point for each intersection in each MAP message that is defined by the latitude, longitude, and elevation of the point.	9

High-level Infrastructure System Requirement	ConOps System Need #
11.2.3.1 The reference point shall be placed within the limits of the defined intersection geometry. For example, the reference point could be a verified point marker (i.e., a surveyed object such as the corner of a controller cabinet or light post) and may be located adjacent to the intersection but within the limits of the node points.	9
11.2.4 The infrastructure shall define lanes in each MAP message.	23
11.2.4.1 The infrastructure shall define connections between lanes in each MAP message.	23, 65
11.2.4.2 The infrastructure shall assign each connection between lanes to a signal group as defined in the SPaT message for the intersection such that RLVW can determine the signal group controlling the anticipated movement of the vehicle.	24, 65
11.2.5 MAP messages shall describe each lane by including node points that contain information about specific points on the ingress and egress to the intersection.	9
11.2.5.1 MAP messages shall describe all node points as occurring on the centerline of lanes or centerline of transitions between lanes (e.g., transition from a through lane to a left-turn lane).	16
11.2.5.2 MAP messages shall describe the location of the first node point of each lane by including offsets in centimeters from the reference point value.	9
11.2.5.3 MAP messages shall describe the location of each subsequent node point by defining offsets in centimeters from the previous node in the lane.	10
11.2.5.4 The infrastructure shall locate the first node point of MAP message ingress lanes along the lane center line and immediately upstream of the stop line.	11
11.2.5.5 The infrastructure shall locate the first node point of MAP message egress lanes at the lane center line immediately downstream of crosswalk or immediately outside the intersection.	12
11.2.5.6 The infrastructure shall include data that enables RLVW to determine the elevation of each node point in each MAP message (e.g., reference point elevation and node specific changes from the reference point elevation).	13
11.2.5.7 The infrastructure shall create each MAP message node point with sufficient accuracy such that, when combined with inherent on-board GPS error, the vehicle OBU can determine the lane of travel (node point accuracy requirement is defined as 0.2-meter accuracy at this time).	16
11.2.5.8 MAP messages shall include sufficient node placement (i.e., number of nodes and locations) to achieve the minimum accuracy requirements for node points located in the vicinity of horizontal curves.	16
11.2.5.9 MAP messages shall include sufficient node placement (i.e., number of nodes and locations) to identify vertical curves on approaches to intersections with vertical curves.	14
11.2.5.10 MAP messages shall include node points that extend a minimum distance upstream of the stop line to a point that provides 10 seconds of travel time at the 85th percentile speed or a speed equal to the posted or statutory speed limit plus 7 mph before approaching vehicles would reach the stop line.	19

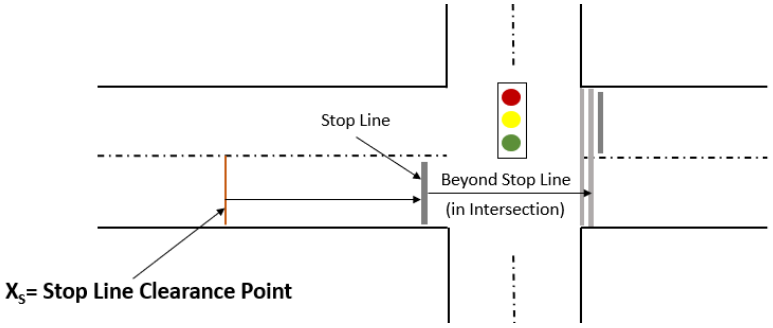
High-level Infrastructure System Requirement	ConOps System Need #
11.2.5.11 In situations where the node point placement for the ingress lane of a Connected Intersections is not able to accomplish the 10 seconds of travel time (described in Requirements 11.2.5.10), the MAP message of the Connected Intersection and related MAP messages of other intersections shall provide a consecutive connection through the upstream intersection to achieve the 10 seconds of travel time.	18
11.2.5.12 MAP messages shall include ingress lanes that do not extend upstream of (i.e., overlap with) other Intersections.	19
11.2.5.13 MAP messages shall include ingress lanes that do not extend upstream of (i.e., overlap with) egress lanes of upstream Connected Intersections.	19
11.2.6 MAP messages shall include a lane width value for each MAP message that represents a reference lane width.	15
11.2.6.1 In situations where an ingress or egress lane width differs more than 5% from the reference lane width, the MAP message shall assign a lane width deviation value to the first node point of each lane that differs by at least this threshold. (Note: 5% is based on the error of the width of two-lane markings (0.2 meters as described in Requirement 11.2.5.7) associated with a 3.6-meter typical lane.)	15
11.2.6.2 MAP messages shall include lane width deviation values for nodes in lane segments that differ from the reference lane width (e.g., areas where the through lane transitions to through and left-turn lane, the transition section of road is often wider than the lanes).	15
11.2.7 MAP messages shall include the posted or statutory speed limit.	78, 79
11.2.7.1 In situations where different lanes have different speed limits, the MAP message shall convey all speed limits as assigned to appropriate lanes.	78, 79
11.2.8 The infrastructure shall include a message counter for each MAP message that represents the numbered version of the MAP message.	20
11.2.9 The infrastructure shall include an intersection revision number for each MAP message that represents the numbered revision of the intersection (note MAP messages may contain multiple intersections this reflects the numbered revision of the intersection).	20
11.3 The infrastructure shall provision and attach security credentials to messages that are up-to-date and based on requirements defined by the SCMS Manager.	22
11.4 The infrastructure shall assemble position correction messages.	21
11.4.1 The infrastructure shall gather position correction data from trusted sources or generate position correction data.	21
11.4.2 The infrastructure shall assemble SAE J2735 messages that include RTCM messages describing position correction data, if the intersection meets the criteria identified in the SPaT Challenge Verification Document[1]. Note: the most benefit from RTCM messages can be achieved with a combination of highly complex SPaT/MAP configuration and open sky, high satellite visibility. More details are available in the reference document.	21
12 Information Broadcast Requirements	

High-level Infrastructure System Requirement	ConOps System Need #
12.1 The infrastructure shall broadcast SPaT messages that conform to the SAE J2735 standard.	1
12.1.1 The infrastructure shall update each signal phase time value in the SPaT messages at an update rate of 100 milliseconds.	1
12.1.2 The infrastructure shall broadcast SPaT messages at a frequency of 10 Hz.	1
12.1.3 The infrastructure SPaT messages shall reflect the current state of the signal indications within 100 milliseconds of a change in the signal indication.	2
12.2 The infrastructure shall broadcast MAP messages that conform to the SAE J2735 standard.	**8**
12.2.1 The infrastructure shall broadcast MAP messages at a frequency of 1 Hz.	8
12.3 The infrastructure shall broadcast RTCM messages that conform to the SAE J2735 standard with minimum elements populated.	21
12.3.1 The infrastructure shall broadcast RTCM messages at a frequency of 1 Hz.	21
12.4 The infrastructure shall sign each message it broadcasts using valid security credentials/certificates that at least meet the minimum requirements as defined by the SCMS Manager.	22

4. Glossary of Terms and Key Definitions

Term	Key Definition
Absolute Time of End of Interval	The SPaT message will eventually know the absolute time of the end of the current interval (and end of next future interval). The J2735 SPaT message will convey this value using available data elements (e.g., min end time and max end time equal).
Connected Intersection	An intersection that is equipped to support V2X communications with current Signal Phase and Timing (SPaT) messages, MAP messages, and messages to support vehicle position correction.
Connected Vehicle	A vehicle (car, truck, bus, etc.) that is equipped with a wireless communication device[2]. A CV uses any of the available wireless communication technologies to communicate with other vehicles on the road (vehicle-to-vehicle [V2V]), roadside infrastructure (vehicle-to-infrastructure [V2I]), and other travelers and the cloud. [3,4] For references in this document, a Connected Vehicle refers to a vehicle capable of executing a RLVW application.
Critical Stopping Distance (CSD)	Distance for vehicle to stop safely at the stop line. Based on: • Perception / reaction time • Actual vehicle velocity • Deceleration of vehicle • Grade of approach • Assume typical road conditions with no ice or gravel
	
Critical Stopping Time (CST)	Time for vehicle to stop safely at the stop line. Based on: • Perception/reaction time • Deceleration of vehicle • Grade of approach • Initial velocity of vehicle • Assume typical road conditions with no ice or gravel
Intersection Clearance Distance	The distance that is used when calculating the time to pass (pass through) the intersection. This may or may not be equivalent to the formal definition of intersection width. RLVW applications may use the ingress and egress node points to determine the intersection clearance distance or may use other approaches for determining this. Intersection clearance distance is considered the distance from the stop bar line to the downstream edge of the crosswalk on the opposite side of the intersection for the approach that the vehicle is traveling. In the absence of a

Term	Key Definition
	crosswalk on the opposite side of the crosswalk, the intersection clearance distance is the distance from the stop line to the downstream stop line on the opposite edge of the intersection for the approach that the vehicle is traveling.
Intersection Clearance Point (X_C)	At the onset of the yellow interval, this is the point beyond which the vehicle will not safely pass the intersection before the red interval. Factor of: • Perception / reaction time • Actual vehicle velocity at start of deceleration • Deceleration rate • Slope / grade of approach • Distance to pass the intersection • Yellow interval time
Interval	Term used to describe the signal indications that drivers would observe as they approach the intersection (e.g., green interval). The term interval refers to the time when a signal indication does not change. For example, the green interval is the time between the onset of green and the onset of yellow.
Next Future Interval	Term used to describe the immediate next interval to be displayed on the signal head (e.g., during green interval, the next future interval is typically yellow). The SPaT message will contain the known end time of the next interval, when it is known, and communicate this as next future interval end time.
Notification	Any advisory, informational, caution, or warning message that is issued by the RLVW application, which may vary by OEM.
Pass	Term used to refer to the vehicle moving past either the stop line or the intersection. Other terms such as 'clear' may be used and refers to the through the intersection and clearing the intersection and pedestrian crosswalks.
Preview Time	Term used to describe an amount of time before the end of the green interval when the absolute end of green interval needs to be known and communicated in the SPaT message for the RLVW application to be able to issue notifications that allow drivers that would not pass the intersection before onset of red to stop safely before the stop line.
Provider Service Identifier (PSID)	The Provider service Identifier (PSID) is a numeric string that is up to 4 bytes used by the IEEE 1609 set of standards to identify a particular application service provider that announces that it is providing a service to potential users of an application or service.
Red Clearance Interval	Term that refers to a specific interval immediately following the yellow interval when traffic from other approaches have not yet transitioned to the green interval. The duration of the red signal indication is a combination of red clearance interval and additional red interval time when the signal remains in red while conflicting traffic is allowed in the intersection. It should also be noted that the red clearance interval is not necessarily all-red indications around the intersection. There may be other traffic that is moving with green signal indications if they do not conflict with the movement of the signal in the red clearance interval. The red clearance interval is optional.

Term	Key Definition
Signal Indication	Term used to describe the current signal control displayed. For example, 'green signal indication' describes situations where a driver approaching the signal would see an active green light.
Stop Line Clearance Point (X_S)	At the onset of the yellow interval, this is the point beyond which the vehicle will not safely pass the stop line before the red interval.
	
To Stop Safely	Expression used to describe timing for the RLVW application to deliver notifications in time for drivers to stop safely when reacting to notifications. The RLVW is intended to alert non-attentive drivers that are at risk of proceeding into an intersection during a red light. The determination on what deceleration rates match 'safely' will vary by OEM.
To Stop Safely and Comfortably	Term used to reference the determination of yellow interval timing for signal controllers. The yellow interval duration is determined to allow attentive drivers to stop safely and comfortably.
Vehicle Clearance Time - Intersection (VCTI)	Time for vehicle to pass intersection. Based on: • Distance to stop line (upstream start of intersection) • Intersection clearance distance (first ingress node to first egress node) • Actual vehicle velocity Note: since this is time for the vehicle to pass the intersection, factors such as reaction time and deceleration are not included.
Vehicle Clearance Time – Stop Line (VCTS)	Time for vehicle to pass the stop line. Based on: • Distance to stop line • Actual speed of vehicle Note: since this is time for the vehicle to pass the stop line, factors such as reaction time and deceleration are not included.
Yellow Change Interval (Y)	Time of Yellow Interval. Based on: • Perception-reaction time • Approach speed (speed limit or 85th Percentile speed) • Deceleration rate (typically 3 m/s^2) • Slope/grade of approach (m/m) • Typically, a value in the range of 3-6 seconds

Term	Key Definition
Yellow Interval End (YIE)	Time until the yellow interval ends, which equals remaining green time + full yellow time. Requires values received from SPaT message.

Appendix: Calculations for Infrastructure Providing End Time of Green Interval

The description in this appendix is provided to support requirement 11.4.1.2. Analysis was conducted for an extensive series of scenarios that represent the following:

- Varying distances upstream of the stop line where the vehicle is located at the onset of the Yellow clearance interval
- Varying speeds of travel; and
- Varying durations of the Yellow clearance interval

Calculations were conducted using driver reaction time of 1 second, an intersection width of 40 meters, zero percent grade, and a presumed braking level of 0.4 g to determine the position of the vehicle at the onset of red interval as either:

- Stopped safely behind the stop line (if braking at 0.4 g)
- Passed (cleared) the intersection (if continuing at the same speed and trajectory) or
- In the middle of the intersection (f continuing at the same speed and trajectory)

Any alterations from these assumed values would result in more or less preview time required. From these calculations, a value was calculated that represents the minimum preview time needed (i.e., time before the end of the green interval that the RLVW application needs the absolute end of green interval time) that would allow the vehicle to either stop safety behind the stop line (considering driver reaction and deceleration rate) or continue at the current speed to pass the entire intersection.

Table 3 represents the minimum preview time required assuming the minimum yellow change interval value.

Table 3: Minimum Preview Time Needed (Seconds) Assuming a Minimum Yellow Change interval.

vehicle speed (mph)	Distance to stop (m)	Time to stop (s)	Minimum Yellow Change Interval	Preview Time Needed (if minimum yellow change Interval time is used)
25	27.09	3.85	3.0	0.85
30	36.33	4.42	3.2	1.21
35	46.84	4.99	3.6	1.41
40	58.62	5.56	3.9	1.62
45	71.68	6.13	4.3	1.82
50	86.01	6.70	4.7	2.02
55	101.62	7.27	5.0	2.22
60	118.49	7.84	5.4	2.43
65	136.64	8.41	5.8	2.63
70	156.07	8.97	6.1	2.83

Table 4 represents the minimum preview time (i.e., time during the green interval when the absolute end of green is known) required based on the combination of yellow change interval time and vehicle speed.[5]

Table 4: Matrix Identifying Minimum Preview Times for Combinations of Speed and Yellow Interval

Yellow Change Interval Duration (sec)	Vehicle Speed (mph)									
	25	30	35	40	45	50	55	60	65	70
3.0	2.50									
3.1	2.50									
3.2	2.50									
3.3	2.50	2.40								
3.4	2.50	2.30								
3.5	2.50	2.20								
3.6	2.40	2.10	1.90							
3.7	2.30	2.00	1.80							
3.8	2.20	1.90	1.70							
3.9	2.10	1.80	1.60							
4.0	2.00	1.70	1.50	1.50						
4.1	1.90	1.60	1.40	1.40						
4.2	1.80	1.50	1.30	1.30						
4.3	1.70	1.40	1.20	1.20						
4.4	1.60	1.30	1.10	1.10	1.10					
4.5	1.50	1.20	1.00	1.00	1.00					
4.6	1.40	1.10	0.90	0.90	0.90					
4.7	1.30	1.00	0.80	0.80	0.80	0.90				
4.8	1.20	0.90	0.70	0.70	0.70	0.80				
4.9	1.10	0.80	0.60	0.60	0.60	0.70				
5.0	1.00	0.70	0.50	0.50	0.50	0.60				
5.1	0.90	0.60	0.40	0.40	0.40	0.50	0.70			
5.2	0.80	0.50	0.30	0.30	0.30	0.40	0.60			
5.3	0.70	0.40	0.20	0.20	0.20	0.30	0.50			
5.4	0.60	0.30	0.10	0.10	0.10	0.20	0.40			
5.5	0.50	0.20				0.10	0.30	0.40		
5.6	0.40	0.10					0.20	0.30		
5.7	0.30						0.10	0.20		
5.8	0.20							0.10	0.30	
5.9	0.10								0.20	
6.0									0.10	
CP (sec) ↑										

Required preview time for combinations of yellow change interval and vehicle speed.
For example, for a yellow change interval of 4.0 seconds and vehicle speed of 35 mph, a preview time duration of 1.5 seconds is required to enable the RLVW application to notify drivers early enough to stop prior to the stop line.

[1] Crash Avoidance Metrics Partners (CAMP), LLC Vehicle to Infrastructure (V2I) Consortium. (October 30, 2017). *SPaT Challenge Verification Document, Version 1.2*. Available at: https://transportationops.org/content/spat-challenge-verification-document.

[2] USDOT. Glossary of Terms for Connected Vehicles 2009 to Present. http://connectedvehicle.itsa.wikispaces.net/Glossary+of+Terms+for+EU-US+cooperation+in+ITS#x-Glossary of Terms for EU-US Cooperation, 2009-Present-Version 7, 2012. Accessed Jan. 1, 2017.

[3] Neudorff, L. G., J. Mason, and J. Bauer. Glossary of Regional Transportation Systems Management and Operations Terms. Transportation Research Board 500 Fifth Street, NW Washington, DC 20001. August 2012. 1–29. http://onlinepubs.trb.org/onlinepubs/circulars/ec166.pdf.

[4] USDOT. Connected Vehicle Basics. https://www.its.dot.gov/cv_basics/cv_basics_what.htm. Accessed Aug. 30, 2017.

[5] Calculations represented in this Figure are for a case of an intersection width of 40 meters, a driver reaction time of 1.0 seconds, and a presumed braking level of 0.4g and a grade of 0%.