CAMP LLC

Vehicle-to-Infrastructure (V2I-4) Consortium

Red Light Violation Warning (RLVW) Application Vehicle System

Concept of Operations

Version 2.4

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Contents

1. Background

Recurring Terms Used in This Document

Several terms are used frequently in this report and are identified below to provide readers clarification on their use. Additional terms are included in the Chapter 11 Glossary and Key Definitions.

The term ***'notification'*** is used to refer to any advisory, informational, caution, or warning message that is issued by the Red-Light Violation Warning (RLVW) application, which may vary by each Original Equipment Manufacturer (OEM).

The expression ***'to stop safely'*** is used to describe RLVW notifications. There are multiple references in the document about the RLVW application delivering 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 early enough to allow the driver to stop the vehicle safely. The determination on what deceleration rates correspond to an outcome of 'to stop safely' will vary by OEM.

The term ***'intersection clearance distance'*** is used to describe actions of the RLVW application to calculate the time for the vehicle to pass the intersection if it maintains the current speed and trajectory. The approach to determining the intersection clearance distance may not be equivalent to the definition of intersection width. For purposes of the RLVW application, the intersection clearance distance is defined as the distance from the upstream edge of the stop line to the downstream edge of the crosswalk on the far side of the intersection for the approach that the vehicle is traveling. In the absence of a crosswalk on the opposite side of the crosswalk, the intersection clearance width is defined as 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. RLVW applications may use the ingress and egress node points to determine the intersection clearance distance or may use other approaches for determining or estimating this value.

The term ***'signal indication'*** is 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. The term ***'interval'*** is 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. The term ***'red clearance interval'*** 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 continues 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 and is described in more detail in this document. The term ***'pass'*** is used to refer to the vehicle moving past either the stop line or the intersection.

1.1 Challenge and Needs Addressed by RLVW

Vehicles running red lights and entering signalized intersections is a safety concern with an average of 700 fatalities and 90,000 injuries each year related to an average of 100,000 red light running related crashes.[1] The following driver needs relate to this identified challenge for improving safety at signalized intersections.

Need #1: Drivers need assistance to help them avoid entering intersections during a red signal indication (i.e., crossing the stop line during a red signal indication).

Need #2: Drivers need assistance to avoid being in the intersection at the start of a red signal indication whenever possible in order to avoid possible conflicts with other vehicles and pedestrians in crosswalks.

Need #3: Drivers need to receive any assistance early enough to stop safely before the intersection stop line.

1.2 Goals and Anticipated Impacts of RLVW Application

Figure 1 illustrates a representative signalized intersection with approaching vehicles. Two lines are used to represent distances upstream of the intersection. These are not constant distances but rather distances that vary by vehicle speed. X_C represents the intersection clearance point. As the signal indication changes from green to yellow, vehicles upstream of X_C will not pass the intersection before the signal indication changes to red if they continue at the same speed. X_S represents the stop line clearance point. As the signal indication changes to yellow, if the vehicle continues at the same speed, X_S is the point beyond which the vehicle will not pass the stop line before the signal indication changes to red. In addition to the two lines, the critical stopping distance (CSD) is represented and is defined as the distance required for vehicles to stop safely. This is also not a constant distance but a function of the perception/reaction time, actual vehicle speed, deceleration properties, and roadway grade.

Figure 1 shows a representative intersection, depicting the following:

- As the signal indication changes to yellow, vehicles downstream of X_C that proceed with the same velocity will pass the intersection before the onset of the red signal indication. If it continues at the same speed, Vehicle 1 will pass the intersection before the onset of the red signal indication.

- As the signal indication changes to yellow, vehicles upstream of X_C that proceed with the same velocity will not pass the intersection before the onset of the red signal indication. If they continue at the same speed, Vehicles 2, 3, 4 will not pass the intersection before the onset of the red signal indication.
- As the signal indication changes to yellow, vehicles upstream of X_S that proceed with the same velocity will not pass the stop line before the onset of the red clearance interval. Vehicles 3 and 4 will not pass the stop line before the onset of the red clearance interval.

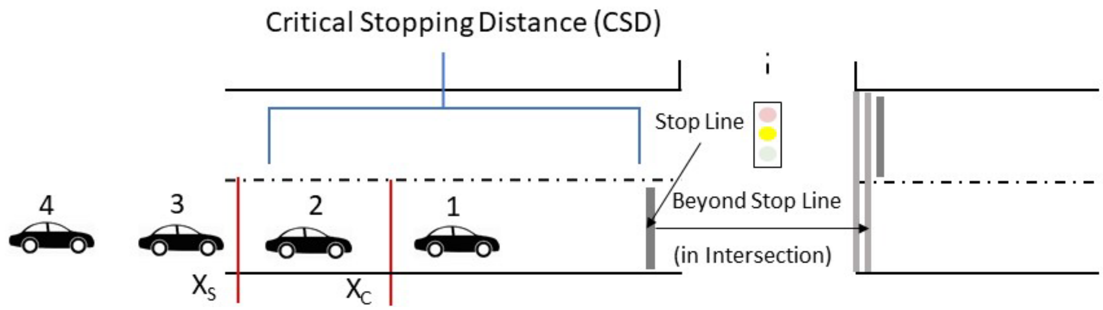


Figure 1: Representative Intersection

The intent of the RLVW application is to influence drivers approaching the intersection that are either unintentionally not stopping during red signal indications or would not pass the intersection before the red signal indication begins. Drivers of vehicles represented by Vehicle 1 in the diagram are not the focus of the RLVW application described in this document as they are expected to pass the intersection before the onset of the red interval. Table 1 identifies examples of driver behaviors that are likely to cause drivers not to stop during the yellow change interval and the impact expected with the RLVW application.

Table 1: Driver Behaviors and Expected RLVW Application Impact

Reasons Drivers Do Not Stop at Red Lights	Expected Impact of RLVW Application
Aggressive driver "thinks they can make it"	Low expectations of influencing drivers
Distracted or inattentive driver does not respond to the Yellow light with adequate time to stop safely.	High expectations of influencing drivers
Uncertainty (e.g., drivers not familiar with the intersection, inexperienced drivers, those that do not know they will not make it safely through the intersection).	High expectations of influencing drivers

RLVW Application Goals

Goal #1: To reduce the number of times that drivers using the RLVW application unintentionally enter signalized intersections when the traffic signal indication is red. Distracted driving is an example of when drivers may unintentionally enter the intersection during red, but other examples (such as drivers unfamiliar with the intersection) are also possible. *(Addresses Need #1)*

Goal #2: To reduce the number of times that drivers using the RLVW application do not pass signalized intersections before the signal indication changes to red (i.e., a portion of the vehicle does not pass the intersection, including crosswalks on the downstream side of the intersection). *(Addresses Need #2)*

Goal #3: That any information or notifications provided to drivers are timely to support safe driving and braking operations, including potentially receiving information and/or notifications during a green signal indication if needed for timely decisions. *(Addresses Need #3)*

Goal #4: To assist drivers with braking through optional assisted or fully automatic braking. *(Addresses Need #1, Need #2, and Need #3)*

The intent of the RLVW application is not to notify drivers solely based on violations from a legal point of view but rather to enhance safety as vehicles approach signalized intersections. An application based on a legal point of view would focus on vehicles illegally entering the intersection when the traffic signal is red. However, this RLVW application aims to reduce the potential for conflicts with other vehicles and pedestrians in the intersection. It is recognized that red clearance intervals are used at some intersections, but research documented in the literature review determined that red clearance intervals are not used uniformly at all intersections.

1.3 Current Situation: Literature Review of Traffic Signal Control Approaches

The literature review for this effort included review of several resources related to signalized intersections. Specifically, this includes the following:

- **National Cooperative Highway Research Program (NCHRP) Report 731: *Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections***. This resource is of interest to safety and traffic engineers and provides comprehensive and uniform guidelines for determining and operating safe and efficient yellow and red intervals for signalized intersections. The guidelines in the report are applicable to state and local agencies.
- The Institute of Traffic Engineers (ITE) ***Guidelines for Determining Traffic Signal Change and Clearance Intervals Recommended Practices – A Recommended Practice of the Institute of Transportation Engineers***. This resource is published as a recommended

practice of ITE. As described in the report's preface, "ITE prepared this report to reflect the current state-of-the-practice and to provide users with a broad overview of key considerations to determine yellow change and red clearance intervals for traffic signals and their application."

- FHWA's ***Manual of Uniform Traffic Control Devices (MUTCD), 2009 Edition***. This document defines the standards used by transportation agencies to install and maintain traffic control devices, including devices such as traffic signals, signs, and pavement markings. Specifically, Section 4D.26 provides information for Yellow Change and Red Clearance Intervals at signalized intersections.
- **NCHRP Report 812: *Signal Timing Manual, Second Edition***. While the first edition of the Traffic Signal Timing Manual[2] included a comprehensive guide for engineers and technicians about signal timing principles, practices, and procedures, the second edition of the Signal Timing Manual has an increased focus on signal system users and their priorities. The second edition introduces an outcome-based approach to signal timing described by an eight-step approach to signal timing (recognizing there is not a one-size-fits-all method for signal timing). Guidance on advanced signal systems and applications are also included in this edition.
- ***Performance of the Advance Warning for End of Green System (AWEGS) for High-speed Signalized Intersections***. This research report describes current practices on placement and warrants for AWEGS, as well as their effectiveness.

1.3.1 Summary of Traffic Signal Controllers in the United States

ITE estimates that there are over 300,000 traffic signals in the United States, as operated by more than 2,000 separate agencies. A significant percentage of the agencies operating traffic signals are responsible for fewer than 50 traffic signals. Finally, approximately 20 percent of signals are managed by state agencies and the remaining 80 percent are managed by municipalities or county agencies.[3]

1.3.2 NCHRP Report 731: Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections

In 2012, the NCHRP produced the NCHRP Report 731 "Guidelines for Timing Yellow and All-Red Intervals at Signalized Intersections."[4] This report provides a comprehensive summary of historical and current approaches to calculating yellow change interval and red clearance intervals, as well as a summary of survey results of agencies operating traffic signal controllers. This report concluded that the duration of yellow change and red clearance intervals has an impact on driver behavior and intersections safety, but it also found that the approaches for determining yellow and red interval varies widely. A survey of approximately 2000 infrastructure owner operators (IOOs) was conducted as part of this research. Of the 268 responses received, 144 responses to the survey indicated that they use the Kinematic Equation to determine yellow and red interval timing. Of the 144 responses:

- 87 responders (60%) indicated the calculated value of the first two terms is allocated to the yellow interval, and the 3rd term is allocated to the red interval.
- 11 responders (8%) indicated that the yellow interval is set at a uniform duration and remainder is allocated to the red interval.
- 15 responders (10%) indicated that the red interval is set at a uniform duration and the remainder is allocated to the yellow interval.
- No responders indicated that the entire time is allocated to the yellow interval (the red interval is not used).
- 31 responders (22%) selected "other" as the approach to allocation of the time using the kinematic equation.

There are various versions of the Kinematic Equation, all of which are based around driver perception/reaction time and deceleration rates of vehicles. The Kinematic Equation used in the NCHRP 731 Project Survey was defined as:

$$\boldsymbol{CP = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V}}$$

Where:
CP = Change Period (s)
t = Perception Response Time (PRT) (s)
V = Approach speed (ft/s)
a = Deceleration rate (ft/s^2)
g = percent of grade divided by 100 (plus for upgrade, minus for downgrade)
W = distance to traverse the intersection (width), stop line to far side no-conflict point along the vehicle path (ft.)
L = Length of vehicle (ft.)

1.3.3 ITE Guidelines for Determining Traffic Signal Change and Clearance Intervals

In March 2020, ITE released "Guidelines for Determining Traffic Signal Change and Clearance Intervals."[5] The stated goal of this document is "…to create a consensus methodology for calculating and evaluating traffic signal change intervals that can be uniformly and consistently implemented by transportation agencies." This document provides a very comprehensive review of current practice regarding yellow change and red clearance intervals by defining the Extended Kinematic Equation to support calculations of both yellow change and red clearance intervals.

The Extended Kinematic Equation is defined as:

$$\boldsymbol{Y \geq t + \frac{1.47\,(V - V_E)}{a + 64.4g} + \frac{1.47V_E}{2a + 64.4g}}$$

$$R = \left[\frac{W + L}{1.47V}\right] - t_s$$

Where:

Y = minimum yellow change interval (sec.)
t = perception-reaction time (sec.)
V = 85th percentile approach speed (mph)
V_E = Intersection entry speed (mph)
a = deceleration rate (ft/s^2)
g = grade of approach (percent/100)
R = red clearance interval

W = distance to traverse the intersection (width), stop line to far side no-conflict point along the vehicle path (ft.)
L = length of vehicle (ft.)
t_s = conflicting vehicular movement start up delay (sec.)

Note: The ITE Guidelines state that the insertion of V_E is included to address the turning vehicles that enter the intersection at speeds lower than the 85th percentile speed. For purposes of through movements, the extended Kinematic Equation reduces to the common form.

In addition to defining the extended Kinematic Equation, the March 2020 ITE Guidelines document addresses several topics related to signal timing by presenting a literature review, description of current practice, and recommendations. The following are brief summaries of the ITE recommendations included in the 2020 document[4] for determining yellow change and red clearance intervals that are most relevant to the RLVW application:

Perception Reaction Time (PRT):

The ITE Guidelines document recommends that a PRT of 1.0 seconds is sufficient for most users. However, locations where other factors such driver age or local scenarios may require local engineering judgment to adjust the PRT.

85th Percentile Approach Speed:

The ITE Guidelines document recommends to use the 85th percentile speed as the approach speed when measured value is available. When 85th percentile speed is not available, the 85th percentile speed may be calculated by adding 7 mph to the speed limit.

Deceleration:

The ITE Guidelines document recommends that 10 ft/s^2 (3 m/s^2) is an appropriate value for deceleration for most uses.

Intersection Width:

The ITE Guidelines document identifies the preferred method of determining intersection width by measuring the total distance from the stop line to the cub-line extension or outside edge of the farthest lane conflicting with vehicular movement, along the vehicle's path. The guidelines go on to indicate that when there is frequent pedestrian traffic or crosswalks, an intersection width that includes the far-side of departure crosswalk may be selected to increase safety for all users, thus, suggesting engineering judgment.

Vehicle Length:

The ITE Guidelines recommend the vehicle length value of 20 ft. (6.1 m) as sufficient for determining yellow interval and red interval. A longer vehicle length may be considered based on local judgment.

Grade:

The ITE Guidelines recommend using a field measurement of the grade for existing roads and using the design approach for proposed roads. Where grade changes over the approach, or is not available, engineering judgment is recommended.

Use of Red Clearance Interval:

The ITE Guidelines recommend calculating the red clearance interval. No specific minimum or maximum value is suggested. Note: Section 4D.26 "Yellow Change and Red Clearance Intervals" of the MUTCD include suggestions for red change intervals.

1.3.4 Manual of Uniform Traffic Control Devices (MUTCD), 2009 Edition

Section 4D.26 in the 2009 edition of the "Manual of Uniform Traffic Control Devices" (MUTCD) describes Yellow Change and Red Clearance Intervals.[6] The MUTCD notes the duration of the yellow change interval and red clearance interval shall be determined using engineering practices, and references ITE's "Traffic Control Devices Handbook" and ITE's "Manual of Traffic Signal Design" (see Section 1A.11). The MUTCD states that duration of yellow change intervals and red clearance intervals shall be consistent with the determined values within the technical capabilities of the controller unit. The duration of a yellow change interval shall not vary on a cycle-by-cycle basis within the same signal timing plan. Likewise, the duration of a red clearance interval shall not be decreased or omitted on a cycle-by-cycle basis within the same signal timing plan (except when a permissive/protected lagging left-turn signal phase for both directions is shown as part of an actuated signal sequence).

Additionally, the MUTCD states that duration of a yellow change interval or a red clearance interval may be different in different signal timing plans for the same controller unit. Specifically, a yellow change interval should have a minimum duration of 3 seconds and a maximum duration of 6 seconds, with longer intervals reserved for use on approaches with higher speeds. Additionally, a red clearance interval should not exceed 6 seconds except when clearing an exceptionally wide intersection.

1.3.5 NCHRP 812: Signal Timing Manual, Second Edition

The second edition of the "Signal Timing Manual" has a section that describes decision zones.[7] The Signal Timing Manual provides definitions to differentiate between two similar concepts: the "dilemma zone" (i.e., regarding yellow change interval timing) and the "decision zone" (i.e., regarding setback detection design). It notes that the decision zone is related not to yellow change interval timing but instead to the human factors regarding driver perception, reaction and judgement. This Manual defines the decision zone as "the distance where each individual driver may make a different decision upon seeing the yellow signal indication; some vehicles may stop and others may go," and illustrates it with Figure 2. The Manual notes that the limits of the decision zone tend to be between 5.5 and 2.5 seconds of travel time from the stop bar, which then is used to calculate distances based on the approaching vehicle speed. The Manual recommends placing one or more detectors at the beginning of the decision zone so that signals can be programmed to not terminate a phase until detected vehicles clear the decision zone. However, decision zone protection would not be offered when a signal phase maxes out or is forced off by signal coordination. Finally, the Manual refers readers to NCHRP Report 731 (described in section 1.3.2 of this document) for more information on dilemma zones.

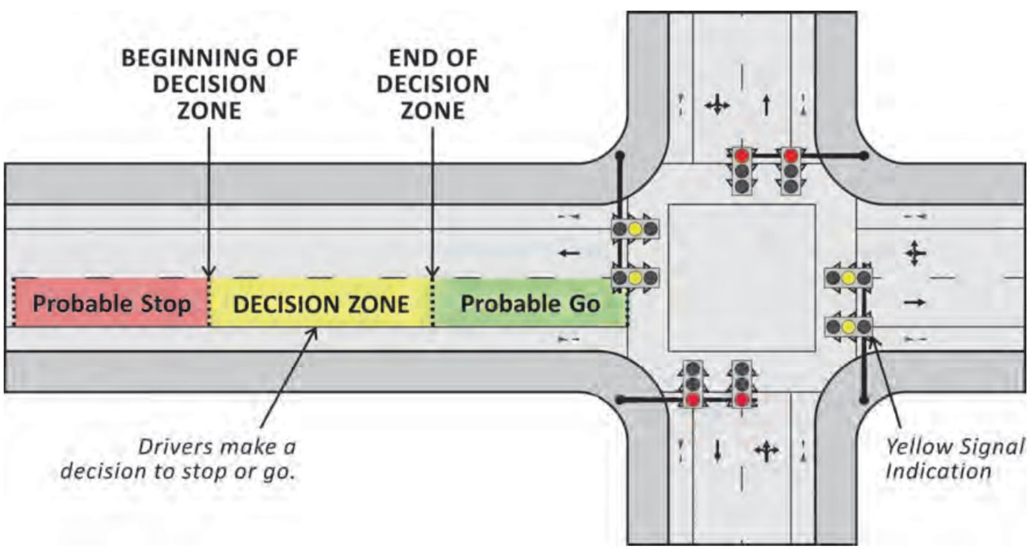


Figure 2: Illustration of Decision Zone from Signal Timing Manual, Second Edition

1.3.6 Performance of the Advance Warning for End of Green System (AWEGS) for High Speed Signalized Intersections

A 2007 paper entitled "Performance of the Advance Warning for End of Green System (AWEGS) for High Speed Signalized Intersections"[8] examined the infrastructure systems that are placed upstream of signalized intersections on higher-speed roadways to provide advance notice to drivers during the green interval that the traffic signal will soon turn to yellow and then red. These types of signs are used in a number of states and internationally. Specifically, these signs say something similar to "BE PREPARED TO STOP WHEN FLASHING" and have beacons that flash about 5 to 6 seconds prior to the onset of the yellow interval on a high-speed approach. These signs help to protect drivers who might otherwise have to choose between rapid deceleration or running a red light given their high speed and the duration of the yellow phase (i.e., the dilemma zone). A study conducted at four locations in Texas showed that AWEGS enhanced dilemma zone protection at the intersections and reduced the red-light running by an average of 40 to 45 percent.

Transportation agencies use warrants as a mechanism to determine where to deploy traffic control devices. For example, the MUTCD contains eight warrants describing situations when intersections should be considered to become signalized intersections. This study identified and summarized a series of warrants for the use of AWEGS that were developed by Canadian transportation agencies. The list below summarizes the warrants for the placement of AWEGS as described in the report:

- A high posted speed limit (e.g., all intersections of 100 km/h [62 mph] for the City of Calgary, Alberta, Canada; 70 km/h [43 mph] in British Columbia, Canada).
- The first signal into a more urbanized area on other relatively high-speed routes (e.g., over 70 km/h [43 mph] in the City of Calgary, Alberta, Canada; any posted speed limit in British Columbia, Canada).
- Roadways with a horizontal or vertical alignment that causes an obstructed view of the signalized intersection (e.g., both the City of Calgary, Alberta, Canada and British Columbia, Canada).
- Roadways where a crash hazard exists that may be corrected by the AWEGS (e.g., in the City of Calgary, Alberta, Canada where the posted speed is over 70 km/h [43 mph]).
- Roadways with a grade in the approach to the intersection that requires more than the normal braking effort (e.g., in British Columbia, Canada).

1.4 Current Situation: Vehicles Approaching Signalized Intersections

This section provides a summary of the current situation as vehicles approach signalized intersections by describing four scenarios of operations. The scenarios described here will be used in later sections to describe the actions of the RLVW application.

1.4.1 Scenario #1: Vehicle Will Pass the Intersection

Scenario #1 describes situations where a vehicle is approaching the intersection at a position that is past X_c and the signal indication changes from green to yellow, as a result, the vehicle should be able to pass the entire intersection (i.e., pass the downstream edge of the intersection and any crosswalks) before the signal indication changes to red by traveling at the same speed. In this scenario, most drivers proceed through the intersection without stopping for the signal change.

As illustrated in Figure 3, Vehicle 1 is downstream of X_C (i.e., they will pass the intersection before the signal indication changes to red).

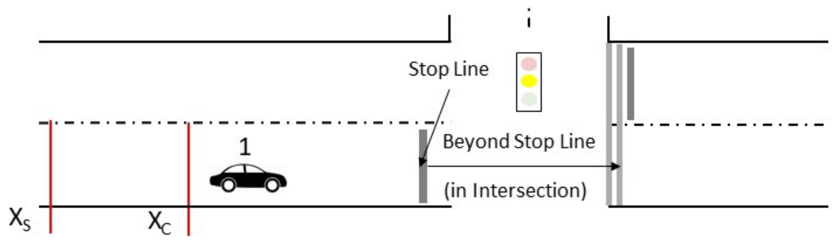


Figure 3: Illustration of Scenario #1

1.4.2 Scenario #2: Vehicle Will Pass the Stop Line but Not Pass the Intersection

Scenario #2, illustrated in Figure 4, describes situations where a vehicle is approaching the intersection past X_s but before X_c as the signal indication changes from green to yellow. If this vehicle continues traveling at the same speed, it will pass the stop line but would not pass the entire intersection (i.e., be in the intersection) before the signal indication changes to red. In this scenario, most traffic laws do not consider this a violation of red-light running laws. However, the impending start of pedestrian traffic and lack of consistent use of red clearance interval introduce additional risks if vehicles are still traveling through the intersection when the signal indication changes to red. For example, agencies operating a leading pedestrian interval (LPI) (i.e., pedestrians get a walk indication before vehicles get a green indication [Signal Timing Manual: Second Edition]). The expected impact of this application is to avoid this scenario by the vehicles slowing during the green signal indication. A warning at or after the onset of the yellow interval may be too late to influence actions to avoid this scenario.

As illustrated in Figure 4:

- As the signal indication changes to Yellow, Vehicle 2 is downstream of X_S (i.e., the vehicle will pass the stop line before the onset of the red interval), and are upstream of X_C (i.e., the vehicle will not pass the intersection before the red interval).
- The CSD is a factor in Scenario #2. The term 'Type I dilemma zone' was originally defined as a theoretical area where the driver is too close to the intersection to stop safely and comfortably yet too far away to completely pass the intersection prior to the end of the yellow change and red clearance intervals. (i.e., the onset of the conflicting green signal indication).[9] The *ITE Guidelines for Determining Traffic Signal Change and Clearance Intervals* document recognizes that there is confusion in the literature about the term "dilemma zone," but states that "A properly timed yellow change interval eliminates this dilemma zone by providing reasonable drivers with the ability to either stop or proceed based on what is physically possible."
- For purposes of understanding how the RLVW application impacts on the current situation, it is important to recognize that notifications to drivers based on the likelihood of them not passing the intersection need to occur prior to the CSD to allow drivers to react and stop safely upstream of the stop line. Research summarized in the NCHRP 731 Report found

that the percentage of drivers that stop at a stop line is at least 90 percent when the travel time to the stop line is at least 5.2 seconds.

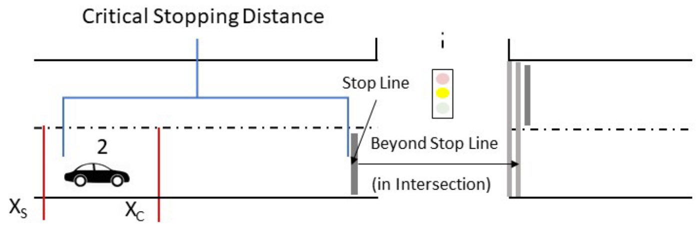


Figure 4: Illustration of Scenario #2

1.4.3 Scenario #3: Vehicle Will Not Pass the Stop Line of the Intersection

Scenario #3, illustrated in Figure 5, describes situations where a vehicle is approaching the intersection as the signal indication changes from green to yellow and the vehicle maintaining its current speed will not pass (i.e., travel beyond) the stop line before the signal indication changes to red. In this scenario, the driver is upstream of X_S. In Scenario #3, if the vehicle continues at the same speed, they will violate red light running laws in all states by entering the intersection during a red interval.

While agency approaches to determining the duration of yellow intervals might differ, ITE recommends an equation and approach to determining the yellow change interval time such that it is at least the minimum time for a driver to make a decision and come to a complete safe stop.[10] A key variable in the determination of yellow interval time is the assumed approach speeds of vehicles approaching the intersection (identified as assumed approach speed). NCHRP Report 731 notes a variety of practices for assumed approach speed, including the approach speed limit and the 85th percentile speed.[11] As noted earlier, ITE recommends using the 85th percentile speed or speed limit plus 7 mph when 85th percentile speed is not available. In locations where this recommendation is followed, vehicles traveling equal to or less than 7 mph over the speed limit, as the signal indication changes to yellow, would either pass the stop line before the onset of the red interval or would be upstream of the CSD and have sufficient time to stop during the yellow interval.

As illustrated in Figure 5:

- Vehicles 3 and 4 are upstream of X_S and upstream of the CSD and therefore have adequate room to stop safely.
- However, based on driver behavior, either driver (Vehicle 3 or 4) may decide to proceed through the intersection without stopping. This may be due to the following:
    - Inattentive driving (e.g., not observing the yellow light)
    - Approach to driving (e.g., deciding they can make it before red)

- A conflict can occur if the lead driver decides to stop while the following driver decides to proceed through the intersection.

In this scenario, a large majority of vehicles will stop, while some will proceed into the intersection. The term 'Type II Dilemma Zone' (also referred to as "Decision Zone") is defined to describe different drivers displaying indecision about whether to stop or go when presented with a yellow signal indication.[12] Specifically, ITE defined the boundaries of this Type II Dilemma Zone as the distance interval in which driver stopping probability was between 10 and 90 percent, which corresponds to between 2.5 and 5.5 seconds from the stop line in most time-based studies.[13] ITE lists the 90th percentile stopping probability as approximately 4.5 to 5.0 seconds from the stop line and the 10th percentile stopping probability as approximately 2.0 to 2.5 seconds from the stop line.[9] In viewing Figure 5, it is important to consider that the position of the vehicles is only representative, as it is a combination of the location and speed of the vehicle that determine both X_S and the CSD.

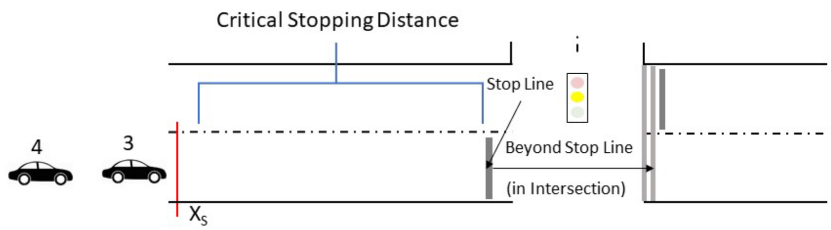


Figure 5: Illustration of Scenario #3

Traffic signal phase timings are designed to provide an adequate duration for the yellow change and red clearance intervals in order to avoid Type I Dilemma Zones whenever possible, thus allowing sufficient time in the yellow change and red clearance intervals for vehicles to pass intersections before cross traffic begins.[12] For purposes of understanding how the RLVW application impacts on the current situation, it is important to recognize that notifications to drivers need to occur early enough such that drivers can react and stop safely (i.e., early enough such that the vehicle has at least the CSD to the stop line).

1.4.4 Scenario #4: Vehicle Approaches a Red Signal Indication

Scenario #4 describes situations where a vehicle is approaching the intersection beyond X_s and the current signal indication is red, as depicted in Figure 6. Vehicles are typically slowing and preparing to stop at the red light. However, at least two situations occur where drivers do not slow and stop:

- Drivers are distracted and may not respond to the red signal indication.
- Drivers may anticipate the signal indication changing to green (perhaps by observing walk signs transitioning to "Don't Walk" or through familiarity with the coordination of signals on the corridor).

Both situations present risks to the drivers and other vehicles and pedestrians on the road.

The CSD is again a factor for vehicles in Scenario #4. The reaction of the driver to decide to stop the vehicle must occur at a distance equal or greater than the CSD upstream from the stop line.

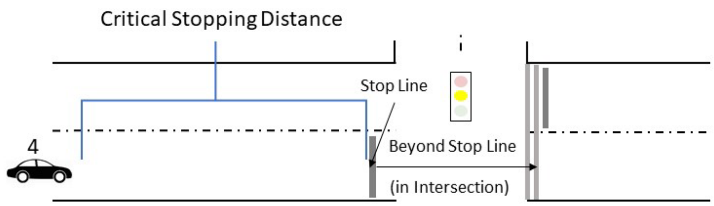


Figure 6: Illustration of Scenario #4

2. RLVW Vehicle System Operational Concepts

2.1 Definition of RLVW Application

This section provides a basic description of the underlying assumptions about the roadway environment, vehicle parameters, and application functionality that apply to all concepts and use cases described in this document. Note that the specific inclusion or exclusion of any roadway type or vehicle class, or description of any parameters, for this document does not preclude changes being made at some future point to modify the proposed application.

2.1.1 Anticipated Roadway Conditions

Definition of connected intersections. The RLVW application will be operational at connected intersections which are defined as intersections that are equipped to support vehicle-to-everything (V2X) communications with current Signal Phase and Timing (SPaT) messages, MAP messages, and messages to support vehicle position correction.

Availability of connected intersections. It is recognized that for the foreseeable future not all signalized intersections will be connected intersections and there will be intersections where the RLVW application does not receive the data needed to provide notifications.

Range of connected intersections. The communication range of the roadside broadcast and the length of the MAP message are two factors contributing to the upstream range that the RLVW application will be operational. Roadside broadcasts are expected to be received at least a distance of 300 meters from the intersection. Guidance for MAP message creation recommends that ingress lane length be long enough to allow vehicles to travel in the ingress lane for at least 10 seconds prior to the stop line. The guidance recommends using 85th percentile speed or the speed limit plus 7 mph when converting 10 seconds of drive time into a distance in meters. Therefore, the RLVW application should expect a communication range of approximately 10 seconds of drive time during most approaches to connected intersections.

Connected intersection data. At a minimum, the SPaT and MAP messages are required for RLVW operation as are valid Security Credential Management System (SCMS) certificates. The position correction message may be required for complex intersections with good Global Navigation Satellite System (GNSS) visibility.[14]

Data or information needs. In addition to this basic definition of a connected intersection, RLVW applications may require additional data or information to enable the application to determine if the data received from the intersection are sufficient to create reliable notifications. Some examples of what information may be needed include:

- **Signal operational mode.** Traffic signals operating in fixed pre-timed mode output deterministic phase end times. Signals operating in fully actuated, semi-actuated, responsive, or adaptive modes may have output time values that do not represent the exact time of the end of the green signal indication. Signals entering or recovering from manual operation mode, "Midnight Flash," or Conflict Flash may also create conflicts between the output time values and the true operational status. An indication of the signal operation mode could enable RLVW applications to determine their operational status.
- **Advanced indication of green end.** In situations where actuated or semi-actuated mode is operational, termination of the green interval can occur without advanced warning. If the vehicle system can obtain a deterministic indication of pending green interval termination a few seconds prior to the transition to the yellow interval, this information could be a decision factor in determining the need for and timing of providing RLVW information to the driver (Scenario 2).

Testing and verification. Infrastructure Owners and Operators (IOOs) will be responsible for testing and verifying the proper functions of connected intersections. Current discussions between IOOs and OEMs are defining test procedures, tools, and reporting approaches that would enable vehicles with a RLVW application to understand if the connected intersection is verified as fully functioning.

Communications. When operational, the RLVW application uses V2X wireless communication signals from traffic control devices to detect situations where notifications are appropriate for the most immediate downstream intersection.

Other assumptions. The RLVW application described in this document also assumes the following:

- The RLVW application will be operating under fair road weather conditions.
- The connected intersection is operational and not overridden by flaggers or power outages. The "status" data element in the SPaT message describes the intersection status.
- Any intersection status that does not provide a deterministic time of the end of the green interval may not fully support RLVW (i.e., Objective 1 may be met but not Objective 2).
- There is no queue before the stop line at the connected intersection.

2.1.2 Anticipated Vehicle Types and Conditions

Vehicle type. This document assumes that the vehicles using RLVW will typically be passenger vehicles with a gross vehicle weight rating (GVWR) of 10,000 pounds or less. Vehicles towing trailers are currently excluded.

Braking. If it is assumed that if RLVW performs braking functions, it will be a vehicle-integrated control system that leverages available features and conditions to affect vehicle dynamics.

Driver responsibility. The driver remains responsible for the safe operation of the vehicle during RLVW operation.

2.1.3 Anticipated Functionality of the Proposed Application

2.1.3.1 Minimum and Optional Functionality

1. RLVW applications will have a common functionality of notifying drivers when their vehicle is very likely to cross the stop line after the signal indication has changed to red, if they maintain the same speed and do not stop. The notification will operate to urge the driver to take an appropriate action to help the driver stop safely before the stop line. *(Goal #1 and Goal #3)*
2. RLVW applications may include functionality of notifying drivers when their vehicle is very likely to not pass the intersection before the signal indication changes to red. OEMs may differ in whether they notify drivers that are not likely to pass the intersection before the signal indication changes to red. *(Goal #2 and Goal #3)*
3. RLVW applications may include functionality of informing drivers when the signal indication changes from green to yellow or yellow to red is imminent. *(Goal #1, Goal #2, and Goal #3)*
4. RLVW applications may trigger brake assist or auto-brake applications (depending upon level of automated driving capability enabled). *(Goal #4)*

2.1.3.2 Clarifications on Functionality

Types of notifications. RLVW notifications are defined in this document as inclusive of any informational, advisory, caution, or warning message that is issued by the RLVW application, which may vary by OEM. OEMs may differ in the types of notifications that are provided (e.g., only warnings, warnings and cautions, etc.).

Presentation of notifications. The determination of when and how notifications are presented to drivers will vary by OEM and may be based on driver selected settings (e.g., aggressive, passive).

- OEMs may vary in the time/distance upstream of the intersection that they provide notifications to drivers.
- OEMs may vary in whether notifications are visual, audio, and/or haptic and also in the specific graphic displays, tones, or pulses that are provided.
- OEMs may vary in modifying or cancelling a planned or issued notification based on driver and vehicle response (e.g., driver applies brakes, vehicle is slowing due to uphill grade, or vehicle is traveling under a specified speed, such as 10 mph).

Suppression of notifications. RLVW may suppress indications to the driver at low speeds to minimize nuisance alerts in situations such as a rolling stop during right turn on red from a combination through / right turn lane.

Intersection congestion. RLVW notifications will assume no congestion and no impeded vehicles in the current travel lane prior to or within the intersection. The RLVW application will not account for congested conditions where other vehicles may "block the box" during a red interval and impede cross-traffic flow.

Focus on through-lane traffic. At this time, RLVW applications will focus on through-lane traffic (i.e., not address left- or right-turning traffic at this time). The decision to focus solely on through traffic is because this application is primarily intended as an aid to drivers who are inattentive. Drivers slowing down to turn, signaling, and/or entering a turn lane are not the intended user.

2.1.4 Topics Not Addressed by the RLVW Application

Movements on red after stopping. The RLVW application described in this document does not address vehicles that come to a stop at the stop line and then proceed into the intersection (either as an allowed right turn on red or through other movements that are not legally allowed).

Other applications. The RLVW application described in this document does not address the potential for other applications that may improve safety at intersections, such as vehicles broadcasting data and receiving data from other vehicles to warn drivers of potential crashes. These would be separate applications, and while they may assist this safety issue, are not addressed in this application description.

2.2 User Perspectives on the RLVW Application

The RLVW application is defined here by plain language descriptions of several perspectives on the application:

1. **Driver Perspective.** The driver perspective represents the drivers' interaction with the RLVW application and does not include details about the calculations performed or decision processes (these are covered in the vehicle system perspective). Recognizing that OEMs will tailor the RLVW application to their specific products, the driver perspective is not an absolute detailed description. Terms like 'may' are used to represent optional aspects of the driver interaction.
2. **Vehicle Perspective.** Once there is consensus on the drivers' interaction with the RLVW application, the vehicle perspective describes what the vehicle system (vehicle and RLVW application) must do to accomplish the driver perspective. This perspective stops short of describing 'how' the vehicle system will work, as the 'how' is a design aspect of the application.

3. **Data Sharing / Data Governance Perspective.** The data sharing / governance perspective describes the overall approach sharing data collected or generated by the RLVW application. This may be a very brief perspective if no data is shared.
4. **Infrastructure Perspective.** The infrastructure perspective describes what role the infrastructure will play in the RLVW application. The infrastructure perspective is derived primarily from the vehicle system perspective as well as the driver perspective and articulates specific needs from the infrastructure.
5. **Drivers of Non-RLVW Vehicles Perspective.** The perspective of drivers of non-RLVW equipped vehicles is described.
6. **Drivers of Other Connected Vehicles Perspective.** The perspective of drivers of other connected vehicles is described.
7. **Pedestrians at Connected Intersections Perspective.** The perspective of people in crosswalks and bicyclists at a connected intersection is described.

Chapters 3-9 provide details of each perspective on the RLVW application.

3. Driver Perspective

3.1 Driver Understanding of RLVW Application

3.1.1 Driver/owner would have access to a definition of the RLVW application and clarifications.

3.1.1.1 The application definition would state that RLVW only functions when V2I communications with the intersection are present.

3.1.1.1.1 Driver travel patterns will vary. Some may rarely encounter connected intersections, and some may often encounter connected intersections.

3.1.1.1.2 Drivers may or may not understand which intersections are connected.

3.1.1.2 Any data collected by the RLVW vehicle would be subject to individual OEM policies on data sharing.

3.1.2 Driver (or potential buyer of the application) may question whether the application reports their violations to law enforcement. This could lead to disengaging the application or not purchasing it (regardless of definitions or messages to the driver).

3.2 Vehicle Start-Up

3.2.1 Driver is not expected to have any actions to initiate or sustain RLVW when starting the vehicle or while driving.

3.2.2 Any indications to the driver, when starting or operating the vehicle, that the RLVW application is functional and operating will be specific to OEM designs.

3.2.3 Driver may need to perform an initial action to either opt-in or opt-out of RLVW as well as set or adjust notification parameters based on ability or comfort level. These actions will be OEM-specific and may involve drivers opting in to (or out of) multiple 'bundled' applications or the RLVW application specifically.

3.3 Vehicle Operating Anywhere Other than on the Approach to a Fully Functioning Connected Intersection

3.3.1 Driver receives no notifications from the RLVW application.

3.3.2 No change from a non-RLVW equipped vehicle.

3.4 Each Time a Vehicle Approaches a Connected Intersection that is Equipped and Operational

3.4.1 As the default, the driver will have no way of knowing if the intersection they are approaching is connected.

3.4.2 The driver may observe an indicator on the intersection infrastructure indicating that it is operating as a connected intersection.

3.4.3 The driver may be notified by either the RLVW application or another application on the vehicle that a connected intersection is detected. This will be OEM-specific for RLVW.

3.4.4 The driver may be notified if RLVW is not receiving data/functioning (e.g., when the signal controller is in manual mode, the intersection is dark, or first responder is flagging traffic, controller is not transmitting SPaT, or security credentials not being valid or current). This will be OEM-specific for RLVW.

3.4.5 The driver will benefit from notifications issued by the RLVW Vehicle System based on the continuous monitoring, receiving, and processing of valid messages from the infrastructure.

3.5 Vehicle Approaches a Connected Intersection in a <u>Through</u> Lane

3.5.1 **Scenario #1: Driver Will Pass Intersection.** If the driver's vehicle (at current speed and trajectory) <u>will</u> pass the intersection before the through movement transitions to the red interval:

3.5.1.1 Driver receives no RLVW notifications.

3.5.1.2 Driver may receive an RLVW notification that is a false positive under certain conditions:

3.5.1.2.1 If the driver accelerates or decelerates rapidly.

3.5.1.2.2 If a traffic signal controller dynamically changes the subsequent traffic signal indication due to surrounding traffic.

3.5.1.2.3 If a traffic signal is controlled manually or a first responder is manually controlling the traffic at an intersection.

3.5.1.2.4 If a traffic signal timing is changed dynamically due to priority passing of other vehicles (e.g., first responder vehicles).

3.5.1.2.5 If there is a significant grade at the intersection approach.

3.5.1.2.6 When one roadway is an overpass of another roadway, with signalized intersections operating for both.

3.5.1.2.7 When the MAP message broadcast by the intersection does not provide clear representation of the movements (e.g., an intersection has many approaches or complex configurations and they are not recorded properly in the MAP message, if recent intersection geometry or control changes have not been updated in the MAP message, when node point spacing in the MAP message is not sufficient for vehicles to properly identify their lane).

3.5.1.2.8 Global Navigation Satellite System (GNSS) / position or accuracy error leading to vehicle MAP matched into wrong lane.

3.5.2 Scenario #2: Driver Will Pass Stop Line but Not Pass Intersection. If the driver's vehicle (at current speed and trajectory) will pass the stop line but not pass the intersection before the through movement transitions to red interval:

3.5.2.1 Driver may receive a RLVW notification.

3.5.2.1.1 If the driver receives a RLVW notification, the timing and method of delivery of the notification will vary by OEM.

3.5.2.1.1.1 The RLVW notification may be in the form of a timely indication when the green signal indication end is imminent, with the intent that the driver either slows or heightens their perception on the road. Both outcomes (slower speed or reduced reaction time) may contribute to avoiding a dilemma zone and allowing safe stopping before the stop line.

3.5.2.1.1.1.1 Notifications when a signal indication change is imminent may be used in specific settings (i.e., settings similar to those where advance warnings of end of green signs have been found to be most effective at slowing traffic and reducing red light running, such as intersections with higher approach speed limits), per OEM-specific designs.

3.5.2.1.2 If the driver receives a RLVW notification, the driver will receive the notification with enough time in advance of the signal indication change to red to allow the driver to react and stop safely behind the stop line.

3.5.2.1.3 The RLVW notification may stop (or does not initiate) if the driver applies the brake or if the RLVW application calculates that the vehicle will stop before the stop line (e.g., on an upward hill, vehicle is slowing without brakes applied).

3.5.2.1.4 The driver may not receive a notification that they will not pass the intersection. The lack of a notification does not imply safe maneuvers. Drivers are responsible for safe operation of the vehicle at all times.

3.5.2.1.5 The anticipated reactions of drivers in this scenario are as follows:

3.5.2.1.5.1 Drivers that receive a notification during the green signal indication are expected to begin reducing their speed prior to the yellow interval and continue to a safe stop before the stop line.

3.5.2.1.5.2 Drivers that receive a notification during the yellow interval are expected to begin braking the vehicle immediately to stop prior to the stop line. Assisted or automated braking may be applied to assist in the safe stop.

3.5.3 Scenario #3: Driver Will Not Pass Stop Line. If the driver's vehicle (at current speed and trajectory) <u>will enter the intersection</u> after the through movement transitions to <u>red interval</u>:

3.5.3.1 Driver will receive a RLVW notification.

3.5.3.1.1 The timing and method of delivery of the notification will vary by OEM.

3.5.3.1.2 The driver will receive the RLVW notification with enough time to allow the driver to react and stop safely behind the stop line.

3.5.3.2 The RLVW notification may stop (or does not initiate) if the driver applies the brake or if the RLVW application calculates that the vehicle will stop before the stop line (e.g., on an upward hill, vehicle is slowing without brakes applied). Driver may not receive a RLVW notification (false negative).

3.5.3.2.1 Even when approaching a connected intersection in the through lane, the driver may not receive a notification that they will not pass the stop line. The lack of a notification does not imply safe maneuvers. Drivers are responsible for safe operation of the vehicle at all times.

3.5.3.3 The anticipated reactions of drivers in this scenario are as follows:

3.5.3.3.1 Drivers are most likely to receive a notification during the yellow interval and are expected to begin braking as soon as the notification is received.

3.5.3.3.2 In situations where a driver receives a notification during the green interval, they are expected to begin reducing their speed prior to the yellow interval and continue to a safe stop before the stop line.

3.5.4 Scenario #4: Driver Approaches a Signal Light that is in Red interval.

3.5.4.1 Driver approaches an intersection that is in red interval.

3.5.4.1.1 Driver will receive a RLVW notification.

3.5.4.1.1.1 The timing and method of delivery of the notification will vary by OEM.

3.5.4.1.1.2 The driver will receive the RLVW notification with enough time to allow the driver to react and stop safely behind the stop line.

3.5.4.1.1.3 The RLVW notification may stop (or does not initiate) if the driver applies the brake or if the RLVW application calculates that the vehicle will stop before the stop line (e.g., on an upward hill, vehicle is slowing without brakes applied).

3.5.4.1.1.4 The driver will receive the RLVW notification with enough time to allow the driver to react and stop safely behind the stop line.

3.5.4.1.2 The driver may not receive a notification that they will not pass the stop line. The lack of a notification does not imply safe maneuvers. Drivers are responsible for safe operation of the vehicle at all times.

3.5.4.1.3 Driver may not receive a RLVW notification if the red interval will end and the signal indication will be green before the vehicle reaches the stop line.

3.5.4.1.3.1 If the driver does not receive a notification, they may perceive RLVW as not working (i.e., the driver doesn't know the light will change to green).

3.5.4.1.3.2 Driver may not distinguish if it is not working because it is not a connected intersection.

3.5.4.1.3.3 Lack of a notification does not imply it is safe to proceed without braking.

3.5.4.1.4 The anticipated reactions of drivers in this scenario are as follows:

3.5.4.1.4.1 Drivers that are approaching or within the CSD that receive a notification during the red interval are expected to begin braking immediately in order to stop safely before the stop line. Assisted or automated braking may be applied to assist in the safe stop. If the red interval ends and the signal indication is green, drivers are expected to stop braking and continue through the intersection.

3.5.4.1.4.2 Drivers that are upstream of the CSD that receive a notification during the red interval are expected to increase attention and begin to reduce vehicle speed, eventually coming to a safe stop before the stop line. If the red interval ends and the signal indication is green, drivers are expected to stop braking and continue through the intersection.

3.6 Intersections in Close Proximity

3.6.1 Driver will only be notified for immediate downstream intersections.

3.6.2 In situations where the ingress node points of a connected intersection extend beyond upstream signalized intersection, there is potential that drivers may receive notifications for the most immediate downstream connected intersection while still being upstream of other signalized intersections (e.g., if the ingress lane extends beyond upstream signalized intersections).

4. Vehicle Perspective

4.1 RLVW Activation and Deactivation

4.1.1 The RLVW application will activate when the vehicle starts, based on the settings selected previously by the driver. Once activated, RLVW will remain active while the vehicle is operating. (3.2.1)

4.1.1.1 The RLVW application will remain inactive if the driver has previously chosen to not opt-in or to opt-out, per OEM-specific designs and settings. (3.2.3)

4.1.1.2 The RLVW application will receive vehicle systems data while activated, including vehicle location data, vehicle speed, and brake activation in order to support RLVW functionality.

4.1.1.3 The RLVW application will deactivate when the vehicle is turned off or if the driver chooses to opt-out at any time.

4.1.2 The vehicle may provide indications to the driver, when the vehicle is starting or operating, that the RLVW application is functional and operating. This will be specific to OEM-specific designs. (3.2.2)

4.1.2.1 The vehicle may provide an indication to the driver, when the vehicle is starting or operating, if the RLVW application experiences an error (e.g., is unable to access or process required vehicle data, or process infrastructure data). (3.2.2)

4.2 RLVW Use of V2X Communications

4.2.1 RLVW vehicle system will only operate with receipt of valid V2X messages that comply with established SAE J2735 standards. (3.3.1)

4.2.1.1 RLVW vehicle system will process valid SPaT and MAP messages.

4.2.1.1.1 RLVW vehicle systems will rely upon SPaT messages to be broadcast at the frequency that matches the smallest time increment of functions of the traffic signal controller, that is 10 Hz. RLVW vehicle systems will rely upon MAP messages to be broadcast at a frequency that enables the vehicle to receive the MAP message within one second of entering the communication range, that is 1 Hz.

4.2.1.2 RLVW vehicle system benefits from position correction data, formatted according to J2735 RTCM messages structure, but may operate without valid RTCM messages. (Note: J2735 RTCM messages "wrap" RTCM messages for sending over the V2X channel. The internal content of the RTCM message is defined by the RTCM standard.)

4.2.1.3 RLVW vehicle system requires that V2X messages include at least the minimum-security certificates. RLVW application will only process messages that are determined to have valid certificates. The in-vehicle security credential processing will perform certificate assessments and only allow the RLVW application access to messages with valid certificates.

4.2.1.3.1 Required security certificates are needed for SPaT, MAP, WSA, WRA, and WSMP.

4.2.2 RLVW will process MAP messages. (3.4.5)

4.2.2.1 RLVW will process MAP messages received.

4.2.2.1.1 RLVW will use the Road Regulator ID and Intersection ID in MAP messages and SPaT messages to ensure both messages are describing the same intersection.

4.2.2.1.2 RLVW will use the MAP message counter to ensure the most recent MAP message is being used.

4.2.2.1.3 RLVW will use the MAP message intersection geometry revision counter to ensure the most recent version of the intersection geometry is being used. Since each MAP message may include multiple intersection geometries, it is possible that one geometry has been updated but another has not. If even one of the intersection geometries has been updated, the overall MAP message counter will be increased.

4.2.2.2 RLVW will process MAP messages to determine the lane of travel.

4.2.2.2.1 RLVW will process the reference point as defined by actual lat/lon and the first node point of each lane as an offset from the reference point. Each subsequent node in a lane is defined as an offset from the previous node.

4.2.2.2.2 RLVW will rely upon sufficient node point accuracy to properly determine the lane of travel.

4.2.2.2.3 RLVW will rely upon the lane width to determine the lane of travel.

4.2.2.3 RLVW will process MAP messages to determine each maneuver that is allowed by the lane of travel and therefore determine if the vehicle is in a lane where through movement is allowed.

4.2.2.4 RLVW will process MAP messages to determine the signal group that provides traffic signal control for the through movement.

4.2.2.5 RLVW will process MAP messages to identify the location (lat/lon) of the stop line for the lane of travel.

4.2.2.6 RLVW will process MAP messages to determine the intersection clearance distance.

4.2.2.6.1 RLVW may use ingress and egress node points to determine intersection clearance distance.

4.2.2.6.2 RLVW may use estimates or average values for intersection clearance distance.

4.2.2.6.3 Individual OEMs may determine intersection clearance distance using different approaches.

4.2.2.6.3.1 OEMs may assume a minimum intersection clearance distance when egress node points are not available or have not been verified.

4.2.2.6.3.2 Intersection testing may include minimum verification of node points.

4.2.2.7 RLVW will process MAP messages to determine the current grade/slope of travel.

4.2.2.7.1 RLVW will rely upon the elevation value associated with each node point.

4.2.2.7.2 RLVW will rely upon node point placement to sufficiently identify vertical curves (i.e., avoid long distances between node points that do not adequately reflect the vertical curve).

4.2.2.8 RLVW will process MAP messages to determine distance to stop line.

4.2.2.8.1 RLVW will rely upon the first ingress node point being immediately upstream of the stop line.

4.2.2.9 RLVW will be able to process lanes defined as computed lanes and revocable/enabled lanes in the MAP message.

4.2.3 RLVW will process SPaT messages. (3.4.5)

4.2.3.1 RLVW will process each SPaT message received for the immediate downstream intersection.

4.2.3.1.1 RLVW will use the Road Regulator ID and Intersection ID in MAP messages and SPaT messages to ensure both messages are describing the same intersection.

4.2.3.2 RLVW will process the SPaT message to determine the Intersection Status.

4.2.3.2.1 RLVW vehicle system may determine not to process SPaT messages (and therefore generate no notifications) based on additional descriptions received from the intersection (e.g., notice of actuated control, lack of advanced indication of green time).

4.2.3.3 RLVW will process the SPaT message to determine the current movement state for the signal group applicable to the vehicle.

4.2.3.4 RLVW will process the SPaT message to determine the time remaining in the current state (green, yellow, red).

4.2.3.4.1 RLVW will process the SPaT message to determine if the time remaining is a true and known value or an estimated value.

4.2.3.5 During a green interval, RLVW will process the SPaT message to determine the fixed yellow interval for the signal group applicable to the vehicle.

4.2.3.6 RLVW will determine the time to red interval for the signal group applicable to the vehicle (i.e., either time remaining in the yellow interval or time remaining in the green interval added to the full yellow interval).

4.2.3.7 RLVW vehicle system will rely on the fact that the infrastructure has verified that the SPaT message matches the actual state of the signal head.

4.2.4 RLVW will process available RTCM messages. (3.4.5)

4.2.4.1 RLVW will process properly formatted RTCM messages. Note: the processing of RTCM messages may be conducted by other applications on the vehicle and not required of the RLVW application.

4.2.4.2 RLVW (or other applications) will use the position correction data in the RTCM messages (if available) to determine correction offsets to apply to the onboard GNSS calculated position of the vehicle.

4.2.5 RLVW will process Security Credentials.

4.2.5.1 RLVW vehicle system will use a public key to verify that the certificate received from the roadside unit (RSU) is legitimate.

4.2.5.2 RLVW vehicle system will compare the certificates received in messages against a repository of revoked certificates or an on-line repository of valid certificates in order to verify that the certificate is not on the list of certificates not to be trusted and determine the current trustworthiness of the sender.

4.2.5.3 RLVW vehicle system will process certificates that accompany each message received from the infrastructure system to determine if the message is from a trusted source, regardless of the payload. This will enable RLVW vehicle systems to receive notice that broadcast was received from a connected intersection regardless of whether the SPaT or MAP messages were valid. When a received payload is empty (e.g., for SPaT and MAP messages) this may support vehicle diagnostics in understanding that the vehicle application is still functioning. (See Section 2.1.1)

4.2.5.4 RLVW vehicle systems will process certificates for SPaT and MAP messages and discard without using any SPaT or MAP messages that do not contain valid and current certificates.

4.3 RLVW Determination of Notifications to the Driver

4.3.1 RLVW notification of valid V2X message receipts.

4.3.1.1 RLVW may notify the driver that a connected intersection is detected. This will vary by OEM. (3.4.3)

4.3.1.2 RLVW may notify the driver if RLVW is not receiving data/functioning (e.g., when the signal controller is in manual mode or not transmitting SPaT). This will be OEM-specific for RLVW. (3.4.4)

4.3.2 If RLVW Vehicle System is approaching a RLVW-enabled Connected Intersection and receives and processes the minimum information to perform RLVW calculations, the following scenarios describe the vehicle system actions.

4.3.2.1 Scenario #1: Vehicle Will Pass Intersection before Red.

4.3.2.1.1 If the vehicle system determines that the vehicle will pass the intersection before the signal indication changes to red (i.e., vehicle clearance time of the intersection is less than or equal to time to the red interval), RLVW will not create a notification. (3.5.1.1)

4.3.2.1.1.1 If the current signal indication is yellow, RLVW will use the remaining yellow time to determine if the vehicle will pass the stop line before the onset of the red interval.

4.3.2.1.1.2 If the current signal indication is green, RLVW will use the time remaining in the green interval and the total time duration of the yellow interval to determine the time to the red interval.

4.3.2.2 Scenario #2: Vehicle Will Pass the Stop Line but Not Pass the Intersection.

4.3.2.2.1 If the vehicle system determines that the vehicle will pass the stop line before the Yellow signal indication ends, if it continues at its current speed, RLVW may also calculate whether it is likely the vehicle will fully pass the intersection prior to the red interval. (3.5.2)

4.3.2.2.1.1 During a yellow interval, RLVW will use the remaining yellow time to determine if the vehicle will pass the intersection before the onset of the red interval.

4.3.2.2.1.2 During a green interval, RLVW will use the time remaining in the green interval and the time duration of the yellow interval to determine the onset time of the red interval.

4.3.2.2.2 If the vehicle system determines that the vehicle is likely to not pass the intersection before the onset of the red interval, the RLVW application may prepare a notification to be issued to the driver to stop the vehicle prior to the stop line to avoid being in the intersection after the signal has turned red. (3.5.2.1)

4.3.2.2.3 The timing and method for issuing a RLVW notification to the driver will vary by OEM. (3.5.2.1.1)

4.3.2.2.3.1 RLVW will issue notifications to drivers with sufficient distance for the vehicle to stop safely at the stop line. (3.5.2.1.2)

4.3.2.2.3.2 Depending upon OEM-specific design and speed of the vehicle, RLVW may require sufficient advanced indication of green end time to perform needed calculations.

4.3.2.2.4 The vehicle system will continue to monitor vehicle data to create, modify, or cancel a planned or issued RLVW notification based on factors such as driver braking and vehicle deceleration/acceleration. (3.5.2.1.3)

4.3.2.2.5 The vehicle system will continue to monitor updated infrastructure data to create, modify, or cancel a planned or issued RLVW notification based on changing conditions. (3.5.2.1.3)

4.3.2.3 Scenario #3: Vehicle Will Not Pass Stop Line if the vehicle (at current speed and trajectory) will enter the intersection after the through movement transitions to red interval**.**

4.3.2.3.1 RLVW will calculate whether it is likely the vehicle will cross the stop line prior to when the signal indication changes to red. (3.5.3)

4.3.2.3.1.1 If the current signal indication is yellow, RLVW will use the remaining yellow time to determine if the vehicle will pass the stop line before the onset of the red interval.

4.3.2.3.1.2 If the current signal indication is green, RLVW will use the time remaining in the green interval and the time duration of the yellow interval to determine the onset of the red interval.

4.3.2.3.2 If the vehicle system calculates that it is not likely the vehicle will cross the stop line before the signal indication changes to red, the RLVW application will prepare a notification to be issued to the driver. (3.5.3.1)

4.3.2.3.3 The timing and method for issuing a RLVW notification to the driver will vary by OEM designs. (3.5.3.1.1)

4.3.2.3.3.1 RLVW will issue notifications to drivers with sufficient distance for the vehicle to stop safely before the stop line. (3.5.3.1.2)

4.3.2.3.4 The vehicle system will continue to monitor vehicle data to create, modify, or cancel a planned or issued RLVW notification based on factors such as driver braking and vehicle deceleration/acceleration. (3.5.3.1.3)

4.3.2.3.5 The vehicle system will continue to monitor updated infrastructure data to create, modify, or cancel a planned or issued RLVW notification based on changing conditions. (3.5.3.1.3)

4.3.3 Scenario #4: Driver Approaches a Signal Light that is in Red Interval.

4.3.3.1 RLVW will calculate whether the vehicle is likely to cross the stop line during the current (red) interval if it continues at the current speed. Note: stop line is used here because the signal indication is already in red.

4.3.3.1.1 RLVW will create a notification if the vehicle is determined likely to cross the stop line while red interval remains. (3.5.4.1.1)

4.3.3.1.1.1 RLVW will use the time mark for the time of red interval end compared to the time to pass the stop line (assuming travel continues at the current speed) to determine if the signal will still be in red interval when the vehicle reaches the stop line.

4.3.3.1.1.2 The timing and method for issuing a RLVW notification to the driver will vary by OEM. (3.5.4.1.1.1)

4.3.3.1.1.3 RLVW will issue notifications to drivers with sufficient distance for the vehicle to stop safely before the stop line. (3.5.4.1.1.2)

4.3.3.1.2 The vehicle system will continue to monitor vehicle data to create, modify, or cancel a planned or issued RLVW notification based on factors such as driver braking and vehicle deceleration/acceleration. (3.5.4.1.1.3)

4.4 RLVW Braking Support

4.4.1 RLVW may interface with vehicle systems to provide assisted braking support or fully automatic braking for drivers. This feature will vary by OEM.

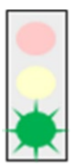
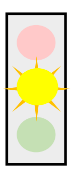
4.4.2 Automatic or assisted braking may be engaged only when a determination is made that:

4.4.2.1 The vehicle will cross the stop line during a red interval (i.e., a red-light violation).

4.4.2.2 An RLVW notification has already been issued to the driver.

4.4.2.3 The vehicle is not decelerating.

4.5 Summary of RLVW Vehicle Actions

Current Signal Indication (what the driver sees)	**RLVW Action Based on Vehicle Location**			
	Upstream of Stop Line Clearance Point	Upstream of Intersection Clearance Point	Upstream of Stop Line	In Intersection
	X_S	X_C	Stop Line	
				
	May notify before CSD if vehicle will not pass intersection or stop line before red, unless driver/vehicle is decelerating appropriately	May notify before CSD if vehicle will not pass intersection, unless vehicle is decelerating appropriately	No RLVW action	No RLVW action
	Will notify before CSD because vehicle will not pass stop line before red, unless driver/vehicle is decelerating appropriately	May notify before CSD if vehicle will not pass stop line and/or intersection before red, unless vehicle is decelerating appropriately	Will notify unless: - vehicle is decelerating appropriately, or - vehicle will pass intersection	No RLVW action
	Will notify before CSD because red light is displayed to driver, unless driver/vehicle is decelerating appropriately	Will notify before CSD, unless vehicle is decelerating appropriately	Will notify unless vehicle is decelerating appropriately	RLVW notifications may terminate once vehicle enters the intersections (OEM-specific design)

5. Data Sharing / Data Governance Perspective

5.1 Data Generated by the RLVW Application on the Vehicle

5.1.1 Data generated by the RLVW application, including any generated or issued notifications, is not expected to be broadcast for consumption by connected intersection infrastructure or other vehicles.

5.1.2 Any data generated by the RLVW application would be subject to individual OEM policies on data sharing.

5.1.3 The governance of this data, including how, when, and by what parties it may be accessed, will vary by OEM and be available to the driver/vehicle owner.

5.2 Other Vehicle Data

5.2.1 Connected intersection infrastructure may receive data from vehicles approaching the intersection (e.g., Basic Safety Message [BSM] that is an anonymous message describing vehicle parameters).

5.2.1.1 Connected intersection infrastructure may process received vehicle data or share it with other IOO systems for other uses or applications.

6. Infrastructure Perspective

6.1 Generating Messages

6.1.1 Connected intersection infrastructure will generate SPaT messages that represent the actual controller status.

6.1.1.1 Connected Intersection infrastructure will verify that the SPaT message matches the actual state of the signal head. (4.2.3.7)

6.1.1.2 Generated SPaT messages will have the following minimal data elements to support RLVW:

6.1.1.2.1 Road Regulator ID and Intersection ID. (4.2.3.1.1)

6.1.1.2.2 Current movement state for each signal group. (4.2.3.3)

6.1.1.2.3 The current state for each signal group. (4.2.3.4)

6.1.1.2.4 Fixed Yellow interval duration broadcast during the green interval. (4.2.3.5)

6.1.1.2.5 The time mark for the interval change of the current signal group.

6.1.2 Connected intersection infrastructure will generate MAP messages that accurately describe the intersection.

6.1.2.1 Generated MAP messages will have the following minimal data elements to support RLVW:

6.1.2.1.1 Road Regulator ID and Intersection ID. (4.2.2.1.1)

6.1.2.1.2 MAP message counter. (4.2.2.1.2)

6.1.2.1.3 MAP message geometry revision counter. (4.2.2.1.3)

6.1.2.1.4 Intersection reference point. (4.2.2.2.1)

6.1.2.1.5 Node offset point of each node. (4.2.2.2.1)

6.1.2.1.6 Lane of travel of each node point. (4.2.2.2.1)

6.1.2.1.7 Maneuver allowed by each lane of travel. (4.2.2.2.3)

6.1.2.1.8 Signal group associated with each maneuver. (4.2.2.2.4)

6.1.2.1.9 Egress node points with initial node point being downstream of the crosswalk. (4.2.2.6.1)

6.1.2.1.10 Ingress node points such that the initial node point of each ingress is located at the upstream side of the stop line at the center of the lane. (4.2.2.6.1)

6.1.2.1.11 Lane width, with each infrastructure provider describing the actual width of each lane at the intersection. (4.2.2.2.3)

6.1.2.1.12 Latitude/longitude/elevation provided for each node point, or the ability to determine these values using a reference point and offsets. (4.2.2.7.2)

6.1.3 Connected intersection infrastructure are expected to generate RTCM messages that includes position correction data.

6.1.4 Connected intersection infrastructure will receive valid and current certificates from certified commercial SCMS providers every two weeks as a minimum.

6.1.5 Connected intersections will use valid certificates to sign all broadcast messages to be sent by unique provider service identifier (PSID) and aligned to the current IEEE PSID registry.

6.1.6 Connected intersections will relate SPaT messages to the UTC time.

6.2 Broadcasting Messages

6.2.1 Connected intersection infrastructure will broadcast the generated SPaT messages that represent the actual controller status. (4.2.3.7)

6.2.2 Connected intersection infrastructure will broadcast the generated MAP messages that accurately describe the intersection.

6.2.3 Connected intersection infrastructure will broadcast any generated RTCM messages that includes position correction data.

6.2.4 Connected intersection infrastructure will use the certificates received from the SCMS to sign the messages it broadcasts.

6.3 Receiving and Using Vehicle Data

6.3.1 Connected intersection infrastructure may receive data from vehicles approaching the intersection (e.g., as a BSM).

6.3.1.1 Connected intersection infrastructure will not receive any information from vehicles about the specific RLVW notifications that were generated or issued to the driver.

6.3.1.2 Connected intersection infrastructure may process received vehicle data or share it with other IOO systems for other uses or applications.

7. Drivers of Non-RLVW Vehicles Perspective

7.1 General Driving Experience

7.1.1 Drivers in a vehicle that does not have RLVW will operate their vehicle as they do now.

7.1.2 Drivers in non-RLVW vehicles traveling in their vehicle down a roadway will observe vehicles approach a signalized intersection similar to vehicles observed today.

7.1.3 Drivers in non-RLVW vehicles may observe a vehicle in front of them begin to slow down in advance of a signalized intersection before the traffic signal has transitioned to yellow interval.

7.1.4 Drivers in non-RLVW vehicles may observe more vehicles being operated in a more conservative manner, such that fewer vehicles are in a signalized intersection when the traffic signal transitions to red interval, resulting in a safer environment.

8. Drivers of Other Connected Vehicles Perspective

8.1 General Driving Experience

8.1.1 Drivers in other connected vehicles traveling in their vehicle down a roadway will observe vehicles approach a signalized intersection similar to vehicles observed today.

8.1.2 Drivers in other connected vehicles will have access to more information from the infrastructure and other vehicles to more safely operate their vehicle than they do now, regardless of whether RLVW is activated or not.

8.1.2.1 Drivers in other connected vehicles will not receive any RLVW notifications based on the actions of other RLVW-equipped vehicles.

8.1.2.2 Drivers in other connected vehicles may be given notifications via other safety applications about an RLVW-equipped vehicle that is violating a red light.

8.1.3 Drivers in other connected vehicles may observe a vehicle in front of them begin to slow down in advance of a signalized intersection before the traffic signal has transitioned to yellow interval.

8.1.3.1 Drivers in other connected vehicles may observe this behavior and not receive an RLVW notification if they have RLVW activated.

9. Pedestrians at Connected Intersections Perspective

9.1 General Walking and Biking Experience

9.1.1 Pedestrians will observe vehicles approach a signalized intersection similar to vehicles observed today.

9.1.2 Pedestrians at a connected intersection will navigate through the intersection on foot or bike as they do now.

9.1.2.1 Pedestrians may have access to more information from the infrastructure and other vehicles to more safely navigate a connected intersection than they do now via V2X applications.

9.1.2.2 Pedestrians may be given notifications via V2X safety applications about an RLVW-equipped vehicle that is violating a red light based on non-RLVW vehicle data (e.g., Basic Safety Messages [BSMs]).

9.1.3 Pedestrians may observe more vehicles being operated in a more conservative manner, such that more vehicles are not in a signalized intersection when the traffic signal transitions to red interval, resulting in a safer environment.

10. Vehicle System Needs

Table 2 defines vehicle system needs. These are precursors to the RLVW Vehicle System Requirements. Each vehicle system needs includes one or more references to numbered lines in the Vehicle System Perspective, allowing readers to understand the origin of the need. As outlined in the table:

- The initial needs (numbers reserved 1-50) describe “what the RLVW Vehicle System needs to receive from external systems”.
- Needs numbered 51 onward describe “what actions the RLVW Vehicle System needs to perform” to achieve the Vehicle System perspective.

Table 2: Vehicle System Needs

#	**Description of Need** **“The Vehicle system needs …”**	**Vehicle System Reference** (or why is this a vehicle system need?)	**Criticality**
Needs below reflect “what the RLVW Vehicle System needs to receive from external systems” (reserved values 1-50)			
1	To receive SPaT messages at an update rate of 10 times per second (i.e., SPaT data is updated and broadcast by the infrastructure 10 times per second).	4.2.3.2, 4.2.1.1.1	Required for all RLVW operations.
2	The data contained in each SPaT message to identify the current state of each signal group (i.e., the current signal interval).	4.2.3.7	Required for all RLVW operations. Testing / verifications approaches are being discussed.
3	Each SPaT message to include valid Road Regulator ID and Intersection ID.	4.2.2.1.1	Required for all RLVW operations.
4	The ‘Intersection Status’ element of the SPaT message to accurately reflect the current operational status of the intersection (e.g., “Fixed Time Operation” or “Traffic Dependent Operations”).	4.2.3.2	Required for all RLVW operations.
5	To receive the fixed time of the yellow interval during the green interval for each signal group that represents the fixed time of the yellow interval for each approach.	4.3.2.1.1.2 4.3.2.2.1.2 4.3.2.3.1.2	Required for all RLVW operations. Required to calculate time to the red interval when the signal is green.

#	Description of Need **"The Vehicle system needs …"**	Vehicle System Reference (or why is this a vehicle system need?)	Criticality
6	To receive a time mark representing the time of current interval end for each signal group.	4.3.2.1.1.2 4.3.2.2.1.2 4.3.2.3.1.2	Required for all RLVW operations. Required to calculate time of the onset of the yellow interval when the signal indication is green.
7	That the time mark representing the accurate end of current interval be received a minimal amount of time before the interval end to prepare notifications.	4.3.2.2.3.2 3.5.2.1.1.1	Required when RLVW will notify drivers who will not pass the intersection before signal indication changes to red.
8	To receive valid MAP messages at a broadcast frequency of 1 time per second.	4.2.2.2, 4.2.1.1.1	Required for all RLVW operations.
9	The latitude, longitude, and elevation of the first node point of each lane to be described as an offset from the reference point values.	4.2.2.2.1	Required for all RLVW operations.
10	The latitude, longitude, and elevation of each subsequent node point in a lane to be an offset of the previous node in the lane.	4.2.2.2.1	Required for all RLVW operations.
11	The first node point of MAP message ingress lanes to be located at the lane center line of the lane immediately upstream of the stop line.	4.2.2.5 4.2.2.8.1	Required for all RLVW operations. Required to calculate distance to stop line. Required to calculate intersection clearance distance.
12	The first node point of MAP message egress lanes to be located at the lane center line immediately downstream of crosswalk or immediately outside the intersection.	4.2.2.6.1 4.2.2.6.2	Required for all RLVW operations. Required to calculate distance to pass intersection. Required to calculate intersection clearance distance.
13	Each MAP message received to include values for elevation of node points.	4.2.2.7.1	Required for all RLVW operations. Required to calculate grade of approach in order to determine stopping distance/time.

#	Description of Need **“The Vehicle system needs …”**	Vehicle System Reference (or why is this a vehicle system need?)	Criticality
14	Each MAP message received to include sufficient node placement (i.e., number of nodes and locations) to identify vertical curves on approaches to intersections.	4.2.2.7.2	Relevant on approaches with vertical curves, used to determine grade of approach when outside a typical value.
15	Each MAP message received to include lane width.	4.2.2.2.3	Required for all RLVW operations. Possibly used by OEMs when determining lane of travel.
16	Each MAP message node to be located at centerlines of lanes and to be accurate enough such that combined with inherent on-board GPS error the vehicle OBU can determine the lane of travel (identified as 0.5 meter accuracy at this time).	4.2.2.2.2	Required for all RLVW operations. Required to identify current lane of travel.
17	Each MAP message to include Road Regulator ID and Intersection ID.	4.2.2.1.1	Required for all RLVW operations.
18	MAP message ingress lanes to not extend upstream of other connected signalized intersections.	4.2.3.1	Required to help ensure RLVW only considers the most immediate downstream intersection when intersections are in close proximity.
19	MAP message ingress lanes to not extend upstream of other signalized (not connected) intersections whenever possible.	4.2.3.1	Required to help ensure RLVW only considers the most immediate downstream intersection when intersections are in close proximity.
20	Each MAP message to include message counter and intersection revision number.	4.2.2.1.2 4.2.2.1.3	Required for all RLVW operations.
21	To receive valid RTCM messages with minimum elements populated at a broadcast frequency of once per second.	4.2.4 4.2.4.1 4.2.4.2	Requested for all RLVW operations. Assists in reducing GPS error in vehicle position. RLVW applications may optionally function without RTCM.

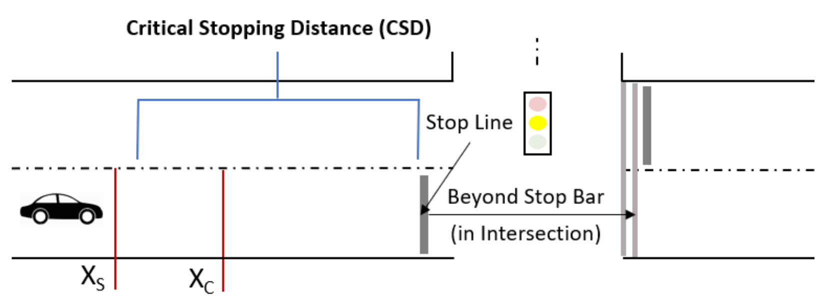
#	Description of Need "The Vehicle system needs …"	Vehicle System Reference (or why is this a vehicle system need?)	Criticality
22	To receive security certificates with messages received from the infrastructure, including the WSA, WRA, and WSMP messages.	4.2.5.1, 4.2.5.2	Eventually required for all RLVW operations.
23	Each MAP message to define connections between lanes.	4.2.2.3	Required for all RLVW operations.
24	Each MAP message to identify which connections are controlled by which signal groups.	4.2.2.4	Required for all RLVW operations.
Needs below reflect "what actions the RLVW Vehicle System needs to perform" (reserved values 51-100)			
51	To activate upon vehicle start-up without driver interaction.	4.1.1	Required for all RLVW operations, per OEM-specific designs.
52	To not activate if the driver/owner of the vehicle has opted out of the application (per OEM-specific designs).	4.1.1.1 4.1.1.2	OEM-specific.
53	To use parameters set by the driver for issuing notifications based on ability and comfort level.	3.2.3	Optional and OEM-specific.
54	To provide indications to the driver about operational status of the RLVW application, per specific OEM-specific designs.	4.1.2	Optional and OEM-specific.
55	To receive and process V2X messages that comply with J2735 standards.	4.2.1	Required for all RLVW operations.
56	To be able to determine the most immediate downstream connected signalized intersection even when receiving J2735 messages from multiple intersections.	4.2.3.1	Required for all RLVW operations.
57	To compare security certificates against a certificate revocation list (CRL) and disregard messages with invalid certificates, according to OEM-specific designs.	4.2.1.3 4.2.5.1 4.2.5.3	Required for all RLVW operations, OEM-specific.
58	To confirm that the SPaT and MAP messages describe a common intersection (using Road Regulator ID and Intersection ID).	4.2.3.1.1	Required for all RLVW operations.
59	To create any OEM-specific notifications to the driver when connected intersections are detected, per OEM designs.	4.3.1	Required for all RLVW operations, OEM-specific.

#	Description of Need **"The Vehicle system needs …"**	Vehicle System Reference (or why is this a vehicle system need?)	Criticality
60	To process vehicle systems data, regarding vehicle speed, location, deceleration, brake activation, and HMI notifications.	4.3.2, 4.3.3	Required for all RLVW operations.
61	To process any available position correction data to adjust vehicle position as determined by on-board GPS, unless performed by other applications on the vehicle.	4.2.4	Required for all RLVW operations.
62	To be able to process MAP messages, including MAP messages containing computed and revocable lanes.	4.2.2.9	Required for all RLVW operations.
63	To determine the lane of travel.	4.2.2.2	Required for all RLVW operations.
64	To determine if the vehicle is in a lane of travel that allows through movements.	4.2.2.3	Required for all RLVW operations.
65	To determine the signal group or groups that provides traffic control for the lane of travel.	4.2.2.3 4.2.2.4	Required for all RLVW operations.
66	To determine the distance to the stop line of the lane.	4.2.2.8	Required for all RLVW operations.
67	To determine the intersection clearance distance. Intersection clearance distance may be determined by distance from first ingress node to first egress node or by OEM-specific designs.	4.2.2.6 4.2.2.6.3	Required for all RLVW operations.
68	To determine the distance to pass the intersection, as the distance to the stop line plus the intersection clearance distance.	4.2.2.6	Optional per OEM-specific designs.
69	To determine the grade of the approach to the intersection.	4.2.2.7	Required for all RLVW operations.
70	To process the SPaT message to determine the current movement state of the through movement.	4.2.3.3	Required for all RLVW operations.
71	To process the SPaT message to determine the time remaining in the current state.	4.2.3.4	Required for all RLVW operations.
72	To process the SPaT message to determine the fixed yellow interval time for the approach of travel.	4.2.3.5	Required for all RLVW operations.
73	To process the SPaT message to determine the time to red interval, relying upon known and true remaining time values.	4.2.3.6	Required for all RLVW operations.

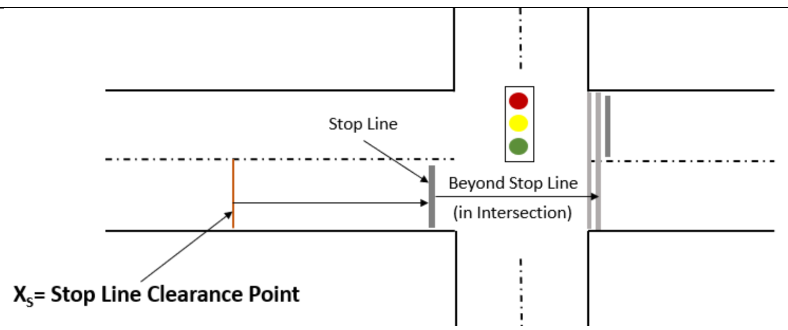
#	Description of Need "The Vehicle system needs …"	Vehicle System Reference (or why is this a vehicle system need?)	Criticality
74	To process the SPaT message to determine if the time remaining is a true and known value or an estimated value.	4.2.3.4.1	Required for all RLVW operations.
75	To determine when the vehicle is not likely to pass the stop line before the signal indication changes to red.	4.3.2.3.1	Required for all RLVW operations.
76	To create and deliver notifications to the drivers who are not likely to pass the stop line before the red interval, based on OEM-specific considerations of braking/deceleration.	4.3.2.3.2 4.3.2.3.3	Required for all RLVW operations.
77	To determine when the vehicle is likely to pass the stop line but not pass the intersection before the signal indication changes to red.	4.3.2.2.1	Optional per OEM-specific designs.
78	To create and deliver notifications to the drivers who are not likely to pass the intersection before the red interval, based on OEM-specific parameters for when to notify drivers and considerations of braking/deceleration.	4.3.2.2	Optional per OEM-specific designs.
79	To determine when the vehicle is approaching a lane in red interval while not decelerating and determine notifications based on OEM-specific calculations.	4.3.3.1	Required for all RLVW operations.
80	To deliver all notifications to drivers while they have adequate time to stop safely before the stop line (i.e., are upstream of the CSD to the stop line).	4.3.2.2.3.1 4.3.2.3.3.1	Required for all RLVW operations.
81	To refrain from delivering notifications to drivers who will pass the intersection before the red interval.	4.3.2.1.1	Required for all RLVW operations.
82	To monitor the status of vehicle braking and cancel any existing (or not issue new) notifications based on OEM-specific algorithms.	4.3.2.2.4 4.3.2.3.4 4.3.3.1.2	Required for all RLVW operations.
83	To continuously process new J2735 messages and vehicle systems data and update any notifications (e.g., canceling existing, issuing new) as appropriate and based on OEM-specific designs.	4.3.2.2.5 4.3.2.3.5	Required for all RLVW operations.

#	Description of Need **“The Vehicle system needs …”**	Vehicle System Reference (or why is this a vehicle system need?)	Criticality
84	To prepare braking assist data to send to other vehicle systems to initiate or terminate braking assist or automated braking operations based on OEM-specific parameters.	4.4.1	Optional per OEM-specific designs.
85	To only create and deliver notifications for drivers in vehicles that are traveling on through lanes (i.e., only signal data for through lanes is required to be processed).	3.5	Optional per OEM-specific designs.
86	To create and deliver information notifications to notify the driver that a signal indication change from green to yellow is imminent.	3.5.2.1.1.1	Optional per OEM-specific designs.
87	To receive information about what message generation and broadcast services are available (e.g., SPaT, MAP, RTCM) and what are not functioning.	4.2.5.3	Required for all RLVW operations

11. Glossary Terms and Key Definitions

Glossary Term	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.
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

Glossary Term	Definition
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 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.

Glossary Term	Definition
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.
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.

Glossary Term	Definition
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 85^{th} Percentile speed) • Deceleration rate (typically 3 m/s^2) • Slope/grade of approach (m/m) • Typically 3-6 seconds
Yellow Interval End (YIE)	Time until the yellow interval ends, which equals remaining green time + full yellow time. Requires values received from SPaT message.

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