Infrastructure System to Support the Reduced Speed Zone Warning – Lane Closure Application

Model Concept of Operations

Version 2.2

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Prepared by:

IOO/OEM Working Group of the Cooperative Automated Transportation Coalition

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List of Acronyms

AASHTO	American Association of State Highway Transportation Officials
ATMS	Advanced Traffic Management Systems
AV	Automated Vehicle
BIM	Basic Information Message
BSM	Basic Safety Message
CAMP	Crash Avoidance Metrics Partnership
CAT	Cooperative Automated Transportation
ConOps	Concept of Operations
CSW	Curve Speed Warning
C-V2X	Cellular Vehicle to Infrastructure
CV	Connected Vehicle
CV-PFS	Connected Vehicle Pooled Fund Study
DMA	Dynamic Mobility Application
DSRC	Dedicated Short-Range Communications
FHWA	Federal Highway Administration
INFLO	Intelligent Network Flow Optimization
IOO	Infrastructure Owners and Operators
ITE	Institute of Traffic Engineers
ITS	Intelligent Transportation Systems
ITSA	Intelligent Transportation Society of America
MUTCD	Manual of Uniform Traffic Control Devices
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol
OEM	Original Equipment Manufacturer
PDMS	Portable Dynamic Message Sign
PID	Personal Information Device
PVD	Probe Vehicle Data
Q-WARN	Queue Warning (application)
RSM	Roadside Safety Message
RSZW-LC	Reduced Speed Zone Warning – Lane Closure
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System
TMC	Transportation Management Center
TTC	Temporary Traffic Control
V2I	Vehicle-to-Infrastructure
VRU	Vulnerable Road User
WZ	Work Zone

1. Introduction

1.1 Background

The American Association of State Highway Transportation Officials (AASHTO), the Institute of Traffic Engineers (ITE), and ITS America (ITSA) working together through the Cooperative Automated Transportation (CAT) Coalition supports state and local public-sector transportation infrastructure owners and operators (IOOs) in actively deploying infrastructure needed to support connected vehicles (CVs) and automated vehicles (AVs). The Federal Highway Administration (FHWA) and Crash Avoidance Metrics Partnership (CAMP) has recently demonstrated several Vehicle-to-Infrastructure (V2I) communications-based safety applications, including Reduced Speed Zone Warning – Lane Closure (RSZW-LC) warning.

The RSZW-LC application advises drivers of an upcoming reduced speed zone, which may include school zones, work zones, and pedestrian crossing areas, and roadway configuration changes or lane closures in work zones where applicable. In general, the in-vehicle RSZW-LC application integrates infrastructure- and vehicle-based data to generate timely messages for the driver to slow to posted speeds and be aware of a lane shift or lane closure.

> **This Concept of Operations describes the data that agencies may provide, and the Infrastructure System used to broadcast this data to Vehicle Systems. How Vehicle Systems use this data to determine appropriate, in-vehicle messages to display to drivers is outside the scope of this document.**

Regardless of whether RSZW-LC and related applications are installed by original equipment manufacturers (OEMs) or are aftermarket products, supporting infrastructure will be needed to broadcast the required information about the current reduced speed and/or lane configuration and how it applies to the defined road segment or area. While the FHWA and CAMP demonstrations of the RSZW-LC application have relied on dedicated short-range communication (DSRC) radio broadcasts, the latency requirements of a reduced speed zone or lane closure do not preclude cellular vehicle to infrastructure (C-V2X) or cloud-based communications mechanisms from also being used, either individually or in combination. The primary goal of the proposed Infrastructure System deployments is to support broadcasts for the RSZW-LC application and other eventual CV applications to be deployed in passenger and fleet vehicles to 'connect' vehicles to the infrastructure in order to promote safety, mobility, and efficiency.

> **The information provided by the IOO to Vehicle Systems is intended for use by Connected Vehicles (CVs). While this information will someday be needed by Automated Vehicles (AVs), the content provided herein is intended only for CVs as a first step toward eventual use by vehicles with higher levels of automation. Likewise, the provision of data by the IOO to the Vehicle System via the Infrastructure System does not guarantee that the Vehicle System will provide a corresponding in-vehicle message to the driver.**

The information provided by IOOs to Vehicle Systems is intended for use by CVs. While this information will someday be needed by AVs, the content provided herein is intended only for CVs as a first step toward eventual use by AVs.

1.2   Purpose

The primary goal of this document is to inform agencies interested in deploying the infrastructure needed to communicate the reduced speed and lane closure information to vehicles, so that it may be presented to drivers today to enhance safety in CVs and as a first step toward eventual use by autonomous vehicles in the future. IOOs may also use this system to provide additional data beyond what is required by the RSZW-LC application in order to support other applications. Agencies pursuing the deployment of Infrastructure Systems to support the RSZW-LC application are encouraged to consider a systems engineering approach towards planning and implementation. Agency deployments of broadcasts to support the RSZW-LC application, either via DSRC, C-V2X, cloud-based communications, or a combination of these, will demonstrate their willingness to support safety applications to OEMs and aftermarket suppliers. Additionally, this deployment experience will allow IOOs to learn the true costs and complexities in order to better assess the long-term deployment considerations for infrastructure that supports the RSZW-LC and similar applications and serve as a learning experience for OEMs. The initial step in the systems engineering approach includes development of a Concept of Operations (ConOps) document.

This **Model Concept of Operations** document is intended for use by those agencies preparing for their deployments of Infrastructure Systems that support the RSZW-LC application.

1.3   Document Overview

This **Model Concept of Operations** document provides a summary of stakeholder groups, system types, stakeholder needs, and operational concepts that describe the sequence of operational events and activities carried out by each stakeholder group. This document describes the data that agencies may provide to Vehicle Systems via a proposed Infrastructure System. The Vehicle Systems can then use that data to determine appropriate, in-vehicle messages to display to drivers.

The intent of this document is to be utilized by state and local agencies and private transportation entities as they begin to plan their deployment of Infrastructure Systems to support the RSZW-LC application. This Model Concept of Operations document is written with flexibility to be adapted to various site conditions and individual practices. It is expected that local customization of the document will be needed to address local specific needs. However, the goal is to assist these agencies with a document that represents initial "model" concepts.

1.4   Scope

This ConOps assumes that the Infrastructure System is being deployed to support variations of the RSZW-LC application within the vehicle. At a minimum, the proposed Infrastructure System is expected to provide data to Vehicle Systems regarding the reduced, current posted speed in advance of a reduced speed zone, which may include school zones, work zones, and pedestrian crossing areas, which may also include a dynamic speed limit. To fully support the RSZW-LC application, the infrastructure is also expected to broadcast information regarding lane closures at a frequency and with range such that Vehicle Systems receive the data at upstream locations and are able to determine and display messages to drivers

in sufficient time to influence actions. The data provided by the IOO via the proposed Infrastructure System is expected to communicate information that is consistent with signage that is placed by IOOs as recommended by the Manual of Uniform Traffic Control Devices (MUTCD), as described in Chapter 2.

An agency need only deploy a basic set of functions of the Infrastructure System to deploy the RSZW-LC application, and is encouraged to tailor this document to fit their specific needs.

1.5   System Boundary

The Infrastructure System supporting RSZW-LC exists in a larger context of other functional components that make up the V2I Connected Vehicle System. The main user of the RSZW-LC application is the vehicle driver. However, the vehicle driver does not interact directly with the Infrastructure System supporting RSZW-LC, but instead interacts with the Vehicle System and therefore is considered an 'indirect user'. An IOO normally is not the entity providing the Vehicle System. Therefore, from the point of view of the Infrastructure System supporting RSZW-LC, *the Vehicle System, not the driver, is considered to be the direct user stakeholder for the in-vehicle RSZW-LC applications*. The information provided to Vehicle Systems is intended for use by CVs. While this information will someday be needed by AVs, the content provided herein is intended only for CVs as a first step toward eventual use by AVs.

Additional individuals and systems will interact with the Infrastructure System as direct or indirect users. Note that pedestrians, including those with disabilities who use a Personal Information Device (PID) to receive information, are not listed as a user group since there are no direct interactions with the RSZW-LC application as it is currently envisioned or deployed. Pedestrian-related needs are a related, possible future consideration for the Infrastructure System supporting the RSZW-LC application for the provision of information regarding the closure or re-location of sidewalks or transit stops due to work zone activities. Similarly, the proposed Infrastructure System, as detailed herein, does not provide warnings to workers about the presence of errant vehicles entering a work area.

Additionally, the proposed Infrastructure System has the potential to be deployed in a variety of other scenarios that are beyond the scope of this effort. For example, incident management may be conducted in a way that is similar to a short-term maintenance lane closure, particularly for a fatal crash that may require a lane closure for several hours with DOT incident responders deploying signage similar to that used in work zones according to the MUTCD. This and other similar scenarios are related, possible future considerations for the Infrastructure System described in this document.

Figure 1. V2I Connected Vehicle Systemillustrates the relationship of the Infrastructure System supporting RSZW-LC, the Vehicle System, and the other direct and indirect users.

Connected Vehicle System for the RSZW-LC Application -- System Illustration

Direct Users
of the Infrastructure System supporting RSZW-LC

Workers

Work Zone Operators

Traffic Engineers

Surveyors and Mappers

Maintenance Techs

ITS, TMC, & Traffic Control Systems

Security Back End

Law Enforcement

Fleet Operators

Infrastructure System supporting RSZW-LC
(the **Focus** of this ConOps Document)

A system that consists of new infrastructure that is added to securely communicate reduced speed and lane closure information to vehicles in order to support applications that interact with drivers.

Vehicle System with RSZW-LC
(a **Direct User of the Infrastructure System supporting RSZW-LC**)

Applications that will be installed on passenger or fleet vehicles to communicate with Infrastructure Systems to provide Basic Safety Messages and receive data about reduced speed zones, using the data to alert drivers, as applicable, about reduced speed zones and/or lane closures.

Indirect Users
of the Infrastructure System supporting RSZW-LC
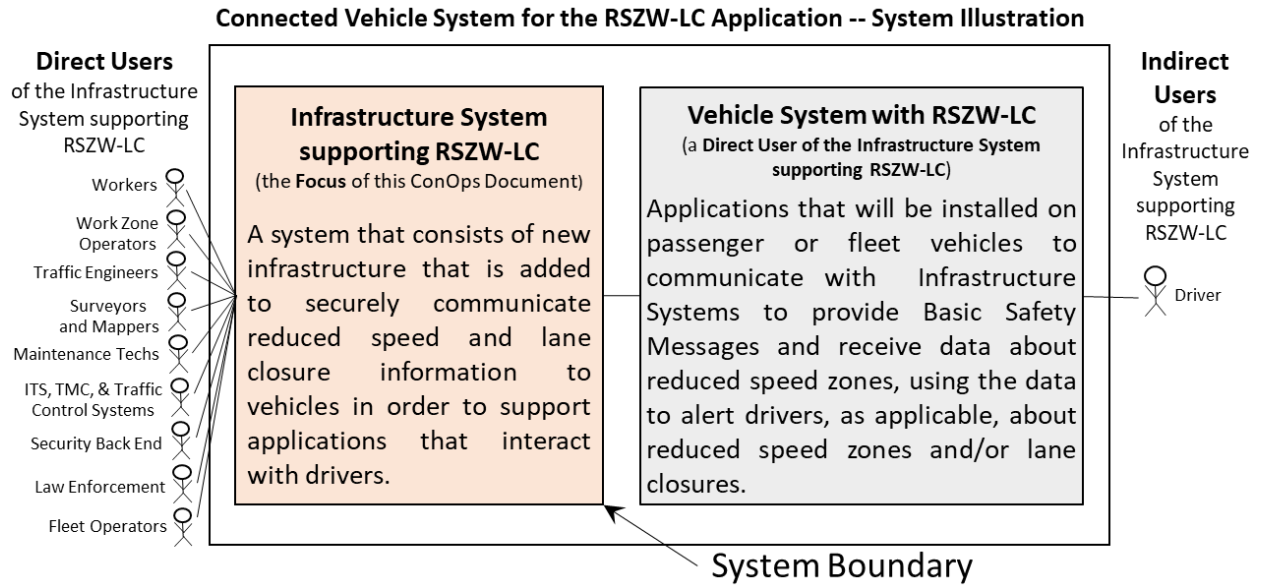
Driver

System Boundary

Figure 1. V2I Connected Vehicle System to Support the RSZW-LC Application

2. Current Situation and Needs

2.1 Current System

It is important to document the transportation infrastructure currently in place in the location where Infrastructure Systems supporting RSZW-LC are to be deployed, as well as the current state of CV applications as envisioned for deployment in Vehicle Systems.

2.1.1 Static and Dynamic Roadside Signage

Existing static signage and intelligent transportation systems (ITS) provide visual indications to drivers and do not communicate electronically with the vehicle, as described below for reduced speed zones and lane closures. Permanently-located reduced speed zones frequently occur in urban areas and generally have access to a wired power source for the provision of flashing beacons, as needed, e.g., in a school zone. However, work zones often occur where wired power is not accessible, particularly in remote, rural areas. ITS deployed in work zones may rely on solar power, for example. The dynamic signage and other ITS in rural work zones may be operated and controlled in the field, without a connection to the transportation management center (TMC), since a dedicated wireline backhaul may be unavailable and cellular connections are sometimes unavailable, unreliable, or can be expensive.

2.1.1.1 Roadside Environment

Note that there is a risk in placing portable or temporary static and dynamic roadside signs and ITS in the field for work zones, both to the workers and the roadside devices given that they may be struck by a passing vehicle or the device could be moved. As such, it is important to consider proper placement of temporary static and dynamic roadside signage to minimize this risk.

2.1.1.2 Reduced Speed Zone Signage

IOOs currently provide reduced speed information to drivers with MUTCD compliant signage. Additionally, guidelines to IOOs for the Advanced Placement of Warning Signs of static roadside signs for reduced speed zone in a variety of conditions, including different speed reductions and presence of merging traffic, are available in MUTCD Table 2C-4.

2.1.1.3 Lane Closure Signage in Work Zones

In addition to a reduced speed limit, work zones for road construction and maintenance activities sometimes have a lane closure. IOOs currently provide lane closure information to drivers with MUTCD signage. MUTCD Figure 6C-1 presents context for the provision of lane closure and related signs by showing the component parts of a temporary traffic control (TTC) zone with a lane closure. Additionally, guidelines to IOOs for placement in typical conditions and Recommended Advance Warning Sign Minimum Spacing for lane closures in a variety of conditions are available in MUTCD Chapter 6H and Table 6C-1, respectively.

2.1.1.4 Related Advisory and Warning Signage

Work zones often include many other TTC warning and advisory signs to address a variety of safety and mobility issues, in addition to signage for reduced speeds and lane closures. The MUTCD Figure 6F-4 includes many static signs that are frequently used in work zones, and provides recommendations for the use of portable dynamic message signs (PDMS). Related information currently provided by IOOs on static and dynamic roadside signs include the following:

- *Advanced notification of work zones*. Static roadside signage typically provides notice of a work zone, e.g., "Road Work 2 Miles".
- *Detour or alternate routing*. Agencies sometimes place detour route signage for some or all vehicles during a work zone. This may occur for trucks given restricted geometries or for all traffic during a closure of an exit or the roadway, for example.
- *Early or late static or dynamic merge*. Agencies sometimes place static or dynamic signage to encourage traffic to merge in advance of the lane closure point (i.e., early merge) or use all lanes up to the lane closure point (i.e., late merge).
- *Lane shift or change in lane geometry*. Work zones often include a lane shift or change in lane geometry. Static roadside signs typically present relevant curve or S-curve information and advisory speed in advance and arrows at the curve, as applicable. The data provided by the proposed Infrastructure System may reflect what is described in the Curve Speed Warning (CSW) application.
- *Queue warning*. PDMS and sensors are sometimes used to display real-time information to advise drivers about a slow-moving or stopped queue of traffic in advance of a work zone. The data provided by the proposed Infrastructure System may reflect what is described in the Queue Warning (Q-WARN) application from the Intelligent Network Flow Optimization (INFLO) bundle of Dynamic Mobility Applications (DMAs).
- *Flagger operations*. Agencies typically place a series of static signs upstream of a work zone with a flagger to warn approaching traffic to slow down and possibly stop.
- *Uneven pavement*. Agencies may place static signs to warn drivers of potential drop offs when lanes are uneven during paving operations in a work zone.
- *Construction vehicles entering / exiting*. Agencies may place static signs to warn drivers of areas where slow-moving construction vehicles will frequently be entering or exiting the roadway. Some agencies deploy PDMS and sensors to provide warnings to drivers in real-time.

2.1.2 Current Infrastructure Components

When tailoring this model document to meet local needs, agencies should assemble and document details about the following components that make up the current system that will be affected by the deployment of infrastructure to support the RSZW-LC application.

- **TMC and Traveler Information Systems** – IOOs use a variety of systems to improve situational awareness and disseminate information regarding reduced speed and lane closures, including Advanced Traffic Management Systems (ATMS), road condition reporting systems (RCRS), and traveler information systems like Highway Advisory Radio (HAR) and 511. IOOs and contractor staff

input data and updates that can ultimately be accessed by travelers for pre-trip and enroute information, as well as other IOO staff. Collectively, these systems contain a variety of data that may be used to support messages for CVs.

- **Work zone ITS** – Many existing work zone ITS devices already use or produce some or all of the real-time data needed to generate messages for CVs. Unlike permanent ITS infrastructure, work zone ITS are placed for temporary or mobile use during construction activities that may occur over the course of several hours or several years, requiring staff to re-program or move system components as construction activities progress, as well as routine monitoring by staff to insure proper system operation. These devices sometimes operate as a closed system that are programmed on-site by DOT or contractor staff. At other times, these devices have a communications link to comprise an integrated system of sensors and signage, which may also be connected to a TMC or back office. Often, the work zone ITS is automated for a specific roadside signage application, such as queue warning or variable speed limits. The data generated by these devices can provide a foundation for generating messages that can be sent to vehicles to support the RSZW-LC application or other applications.

- **Backhaul Communications** – Many locations with a reduced speed zone or work zone may have existing backhaul communications capabilities, either wireless or a combination of short-range wireless and wireline connections. Backhaul communications would allow for monitoring and configuring the Infrastructure System from a central location, which could save staff time and vehicle use in operating and maintaining the Infrastructure System. The agency could also leverage backhaul communications to utilize real time data from the Infrastructure System for other purposes in addition to broadcasting it to vehicles.

2.1.3   Current V2I and V2V Message Formats

The following V2I and Vehicle-to-Vehicle (V2V) message formats are currently available and envisioned to support the RSZW-LC application, either directly or indirectly.

- **Road Safety Message** – The Vehicle System needs the Infrastructure System to communicate data so that the vehicle can determine worker presence, reduced speeds, and other obstacles, which may be accomplished by using the Road Safety Message (RSM). The Connected Vehicle Pooled Fund Study (CV-PFS), in cooperation with CAMP, is developing content for a RSM to replace the Basic Information Message (BIM), and this content will be offered as input to the eventual RSM standard expected to be developed by SAE.
- **Basic Safety Message** – The Vehicle System is envisioned to provide the Basic Safety Message (BSM), which includes vehicle speed and trajectory information, to the proposed Infrastructure System. The BSM broadcast is not directly part of the RSZW-LC application, but there is an understanding that CV equipped vehicles are likely to broadcast the BSM that could be used to support the application.
- **Probe Vehicle Data** – The Vehicle System is also envisioned to provide Probe Vehicle Data (PVD) to the proposed infrastructure system. The broadcast of PVD is not directly part of the RSZW-LC

application, but CV equipped vehicles are likely to broadcast PVD that could be used to support the application.

2.2   Stakeholders Impacted by the Proposed System

Many stakeholders would interact with and/or be impacted by the deployment of broadcasts that support the RSZW-LC application. Travelers could experience increased mobility or safety as a result of the RSZW-LC application deployed to utilize the broadcasted information, while other stakeholders would be responsible for operating and maintaining the new equipment and systems. Below is a list of the primary stakeholder groups who will most directly interact with the equipment deployed or the RSZW-LC application supported by the broadcast information. Their needs will serve as the basis for developing functional requirements for the broadcast information.

2.2.1   Indirect User Stakeholders

As illustrated in Figure 1, the Infrastructure System supporting the RSZW-LC application has one indirect user group identified. These users are identified as indirect because they do not interface with the Infrastructure System directly (rather they interface with Vehicle Systems). Indirect users include:

- **Drivers**. This includes a range of roadway users – e.g. passenger vehicle drivers, commercial drivers, and transit vehicle operators – who travel through the work zones or reduced speed zones where information will be broadcasted to Vehicle Systems. Drivers will not directly interact with the Infrastructure System supporting the RSZW-LC application, but rather with the Vehicle System that is outside of the Infrastructure System, and in most cases will be provided by others rather than by infrastructure owners & operators (IOOs). Therefore, the Vehicle System is considered to be the direct user and the driver is an indirect user.

2.2.2   Direct User Stakeholders

User stakeholders describe those **_individuals or systems_** that will interact directly with the Infrastructure System that supports the RSZW-LC application. These include the following:

- **Vehicle System.** This includes vehicles and aftermarket devices in vehicles equipped with the RSZW-LC application, as well as any other CV applications that may use information broadcast by the proposed Infrastructure System. The Vehicle System will also provide the Basic Safety Message (BSM), which includes vehicle speed and trajectory information, to the proposed Infrastructure System. Note that the BSM broadcast is not described in this ConOps as a part of the RSZW-LC application, but rather the general Vehicle System understanding that CV-equipped vehicles are likely to broadcast the BSM.

- **Work Zone Operators.** This includes the individuals that are responsible for the design and inspection of the work zone traffic control, including static and dynamic signage, as well as any related equipment or traffic mitigation strategies. Individuals in this user group also setup and manage traffic control at the work zones and reduced speed zones included in the broadcasts that support the RSZW-LC application. These individuals monitor work zones for queues and could use average speed data

received in BSMs by the proposed Infrastructure System to help determine whether additional static signage or ITS devices are needed to help mitigate work zone impacts. These individuals work as contractors, third-party ITS contractors, or agency staff. Additional data required for the RSZW-LC application will be generated by this user group, as needed.

- **Traffic Engineers.** This includes individuals responsible for the placement and operations of static and dynamic signage related to reduced speed limits in <u>non-work zone</u> scenarios. Individuals in this user group may manage static speed limit signage with dynamic elements, such as flashing beacons to indicate timing for reduced speed limits in a school zone, "Your Speed is…" trailers that display the vehicle speeds to drivers passing the sign, or automated speed enforcement equipment in reduced speed zones. These individuals could use average speed data received in BSMs by the proposed Infrastructure System to help determine whether additional static signage or ITS is needed to help manage speeds in non-work zone reduced speed zones.

- **Surveyors and Mappers.** This includes either agency or contracted staff who are responsible for providing any detailed location information about the reduced speed zone, including alternate route information required for work zones or the creation and maintenance of required location data.

- **Maintenance Techs.** This includes contracted or agency staff that perform routine maintenance of field equipment and also monitor and respond to maintenance issues as they arise in the field.

- **Construction and Maintenance Workers.** This includes contracted or agency staff who execute construction and maintenance activities in work zones, necessitating reduced speeds and possible lane configuration changes or closures. Construction and maintenance worker presence may influence the legal speed limit in the zone, and workers may collaborate with work zone operators to move the Infrastructure System or update data the Infrastructure System or the ITS and traffic control systems that provide data to the Infrastructure System.

- **ITS, TMC, and Traffic Control Systems.** This broadly includes the sensors, PDMS, and other technology systems deployed for a work zone, and the speed detection and display devices for reducing speeds in other areas, as well as traffic conditions databases, ATMS, and other applications and distribution systems the IOO uses to collect, store, process and distribute real-time and archived traffic data.

- **Security Back End.** This includes the Security Credentials Management System for connected vehicle message security and any agency network security systems. The Vehicle System and the Infrastructure System supporting RSZW-LC applications are both users of the Security Back End.

- **Fleet Operators.** This includes operators and managers of fleets that may be equipped with Vehicle Systems and CV applications that use the broadcast information. Fleet operators may also receive the information broadcast by the Infrastructure System via center to center communications, allowing them to make adjustments to schedules or routes.

- **Law Enforcement.** This includes officers in the field or dispatch staff in the office who may view BSM data to identify locations where average speeds are relatively high compared with the posted, reduced speed limit and enforcement may be needed to help ensure safe conditions.

2.3 Stakeholder Needs

This section presents model stakeholder needs based on input and feedback from agencies deploying the RSZW-LC application and the use cases illustrated in the previous section's use case diagram. It should be noted that deploying broadcasts with information for the RSZW-LC application alone does not address stakeholder needs, however the broadcasts are supporting infrastructure to multiple possible CV applications that could address the needs. The needs are identified by first describing a challenge facing one or more of the stakeholders (column 1). Based on each challenge, one or more needs (column 3) are described and will serve as the basis for operational concepts, requirements, and design. Each need is also numbered (column 2) for identification and traceability purposes. The need identification allows each subsequent reference to be traced back to an original need and corresponding challenge.

In order to distinguish the needs for a basic functioning Infrastructure System capable of broadcasting messages with the minimum information to support RSZW-LC, additional needs shown in italics should be considered optional by agencies using this model document. These needs would depend upon the intended deployments at each location.

2.3.1 Indirect User Needs

The needs of these indirect users are captured in Table 1 below and presented before the needs of other user groups because they represent the underlying needs for ultimately deploying the Infrastructure System to support the RSZW-LC application, and also related systems.

Table 1. Indirect User Needs for Infrastructure Systems that Support the RSZW-LC Application

Challenge	Need ID	Need
Indirect User Stakeholder Needs		
Driver / Riders in AV Needs		
Vehicles encroaching in work zone areas where workers are present is a safety concern, with an average of 700 fatalities each year, 90,000 injuries related to an average of 100,000 work zone encroachment crashes.[i]	1.1	Drivers need to be made aware of lane closures and lane configuration changes when a work zone is present, including mobile work zones. Drivers need to be alerted in time for appropriate action to be taken.
Vehicles speeding through reduced speed zone areas such as work zones, school zones, or towns endanger vulnerable road users (VRUs) such as workers, children, or pedestrians who are present, as well as other drivers.	1.2	Drivers need to be made aware of reduced speed zones in advance of and through the area where conditions warrant a slower speed, including areas with a dynamic speed limit. Drivers need to be alerted in time for appropriate action to be taken.
Vehicles approaching work zone areas do not always have access to current, timely, and accurate information that could help improve work zone safety and mobility.	1.3	Drivers need current, timely, and accurate information in advance of the work zone to be made aware of current work zone conditions.

2.3.2 Direct User Needs

The needs of the direct users are captured in Table 2 below, including those of Vehicle Systems, work zone operators, traffic engineers, maintenance staff, ITS and traffic control systems, the security back end, and fleet operators, as well as performance needs.

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[i] https://ops.fhwa.dot.gov/wz/resources/facts_stats/safety.htm

Table 2. User Stakeholder Needs for Infrastructure Systems that Support the RSZW-LC Application

Challenge	ID	Need
User Stakeholder Needs		
Vehicle System Needs		
Vehicle Systems need information from the Infrastructure to properly inform the driver when approaching a reduced speed zone.	3.1	The Vehicle System needs current posted speed and lane configuration information about the zone so that the vehicle applications can determine the appropriate alert message(s) related to speed and lane configuration on their approach to the zone.
	3.2	The Vehicle System needs location data of the zone so that the vehicle system can determine the position of the vehicle relative to the reduced speed zone, the current lane the vehicle is traveling in, the location of lane closures and any changed lane configurations, e.g. lane shifts.
	3.3	The Vehicle System needs data so that the vehicle can determine worker presence, reduced speeds, and other obstacles. This may be accomplished within a Roadside Safety Message (RSM) from the infrastructure.
	3.4	*The Vehicle System sometimes needs position correction data so that the vehicle can accurately make use of the location data (e.g. determine which lane is impacted, determine when lane changes begin, etc.).*
Vehicle Systems need current, timely, and accurate information that describes as much detail about the work zone as possible.	3.5	The Vehicle System needs updated information broadcasts as roadside signage is changed so that the information provided to Vehicle Systems is consistent with and does not contradict roadside signs. Note an exception could occur during transition periods when the work zone is being set up or has ended and roadside signage does not accurately reflect the current state of the lane closure.
	3.6	The Vehicle System needs any provided information that is not available on roadside signs (e.g. if workers are present in the work zone or children are present in a school zone) to be consistent with and not contradict roadside signs (e.g. roadside signs may display "Speed limit 30 MPH when workers are present", the received information could include the presence of workers and confirmation that the speed limit is 30 MPH). In this example, the received information does not contradict the roadside signs and supplements / adds value.
Creating Speed-related Performance Measures and traveler information, such as work zone travel times, requires information about vehicle trajectories.	3.7	*In order to support work zone operations and traveler information, the Vehicle System needs the Infrastructure System to accept wireless messages from the vehicles containing BSM and PVD.*

Challenge	ID	Need
Work Zone Operator and Traffic Engineer Needs		
Work zone operators and traffic engineers, in a work zone or other reduced speed zone location respectively, will be responsible for managing, configuring, and monitoring the overall operations of broadcasts in locations with a reduced speed and/or lane closure.	4.1	Work zone operators or traffic engineers need the Infrastructure System that supports the RSZW-LC application to provide a mechanism for them to manage and configure the system so that it performs the functions as designed.
	4.2	*Work zone operators need the Infrastructure System that supports the RSZW-LC application to be portable and readily reconfigured for temporary applications.*
	4.3	Work zone operators or traffic engineers need the Infrastructure System that supports the RSZW-LC application to provide a mechanism to define and configure the location data that describes the reduced speed zone, lane geometry, and approaches in a format that can be communicated to other systems.
Work zone operators and traffic engineers, in a work zone or other reduced speed zone location, are ultimately responsible for the data communicated through the Infrastructure System that supports the RSZW-LC application and therefore must have access to verify the accuracy of the information being broadcast.	4.4	In order to verify the accuracy of the information being broadcast, the work zone operators or traffic engineers need the Infrastructure System that supports the RSZW-LC application to provide a mechanism for them to monitor and receive reports of the data being sent and received.
Maintenance Tech Needs		
Vehicle-based safety applications will rely on communications from Infrastructure Systems that support the RSZW-LC application on a continuous 24/7 basis.	5.1	Maintenance techs need the Infrastructure System that supports the RSZW-LC application to provide local, and remote when available, diagnostic information and logs to help them diagnose and repair malfunctions.
	5.2	Maintenance techs need the Infrastructure System that supports the RSZW-LC application to provide a mechanism for locally, and remotely when available, resetting the system and updating software and firmware.
	5.3	Maintenance techs need to be able to update the operating system or the firmware for all, some, or individual infrastructure systems based on a defined schedule.
	5.4	Maintenance techs need to be able to configure many, multiple, or individual infrastructure systems for field deployment through a management platform.
Without notification, maintenance techs will not be able to detect and respond to malfunctions or outages of the Infrastructure System that supports the RSZW-LC application.	5.5	Maintenance techs need the Infrastructure System that supports the RSZW-LC application to provide configurable alerts when it detects improper system operation.

Challenge	ID	Need
ITS and Traffic Control System Needs		
Deployed ITS and Traffic Control Systems have limited abilities to communicate the needed data describing reduced speed zones and lane configurations directly to Vehicle Systems, and therefore rely on the Infrastructure System that supports the RSZW-LC application.	6.1	*In order for the Infrastructure System that supports the RSZW-LC application to communicate current data to vehicles to support in-vehicle applications, the ITS and Traffic Control Systems need supplemental communications, i.e., the Infrastructure System, to accept current speed limit (or advisory speed limit), worker presence, and lane geometry information, which may be input by the work zone operator or traffic engineer. This allows the Infrastructure System to supplement existing ITS and Traffic Control Systems, but the Infrastructure System could also be a standalone system.*
Speed-related performance measures and traveler information would benefit from increased information about vehicles.	6.2	*In order to support performance measures and traveler information, ITS and Traffic Control Systems need the Infrastructure System that supports the RSZW-LC application to communicate BSM and PVD received from vehicles.*
Security Back End Needs		
There is a risk of unauthorized systems imitating the infrastructure and sending inappropriate data to vehicles.	7.1	Security back end systems need the Infrastructure System that supports the RSZW-LC application to accept security credentials so that they can be attached to messages sent to Vehicle Systems.
	7.2	*Security back end systems need the Infrastructure System that supports the RSZW-LC application to accept certificate revocation lists identifying security credentials that should be considered invalid if received from Vehicle Systems.*
There is a risk of unauthorized systems imitating vehicles and sending data to the road side equipment.	7.3	*In order to protect the security of the RSZW-LC related messages, Security Back End Systems need the Infrastructure System that supports the RSZW-LC application to verify the authenticity of security credentials received from Vehicle Systems.*
There is a risk of unauthorized access to devices on the agency network.	7.4	Security back end systems need the Infrastructure System that supports the RSZW-LC application to provide control of access.
The agency must protect the ITS and traffic control devices, network, and central system that interfaces with the Infrastructure System that supports the RSZW-LC application from unwanted access or malicious intents.	7.5	To manage network security and configuration, the security back end needs the Infrastructure System that supports the RSZW-LC application to provide a means to configure address, access control, [etc.]

Challenge	ID	Need
Performance Needs		
Drivers do not limit their driving to geographic areas, specific times, favorable weather conditions, or specific agency operated roadways.	8.1	Vehicle Systems need the Infrastructure Systems that support the RSZW-LC application to send and accept data by following common standards wherever they are deployed, in order to allow Vehicle Systems to function as intended without regard to geographic location, time, or weather conditions.
Safety or mobility applications that are not reliable or functionally sound will not be accepted by drivers.	8.2	Vehicle Systems need Infrastructure Systems that support the RSZW-LC application to communicate data so that it is received at upstream locations frequently enough, timely enough, and accurately enough that will allow appropriate functionality.
Vehicle Systems that lack accurate location data cannot provide adequate information to drivers.	8.3	Vehicle Systems need positioning and zone location data to be accurate enough to reliably determine the distance of the vehicle from the zone start point.
Vehicle Systems that incorrectly assign a vehicle to a lane cannot provide adequate information to drivers.	8.4	*Vehicle Systems need location data to be accurate enough to reliably determine the lane of travel and distance of the vehicle from various geometric features of the zone.*
	8.5	*In situations where position correction data is broadcast, Vehicle Systems need the correction data to be accurate enough to enable the Vehicle System to correct their position in order to properly identify the lane of travel the vehicle is in and to identify the open lane(s) of travel through the work zone.*
Any systems interfacing with ITS or traffic control devices introduce a risk that the ITS or traffic control could be exposed to accidental or intentional interference.	8.6	Infrastructure Systems that support the RSZW-LC application need to not interfere with the operations of the ITS or traffic control devices, except in ways that are approved.
	8.7	All users of the Infrastructure Systems that support the RSZW-LC application need the Infrastructure System to operate properly in the roadside physical, electrical, radio frequency and support environment.
Fleet Operator Needs		
Fleet operators can use current lane closure information when planning trips for fleet vehicles.	9.1	*Fleet operators require Center-to-Center communications to make informed dispatch decisions and share information with fleet vehicles regarding the presence of lane closures that could negatively impact mobility.*

3. Operational Concept for the Infrastructure System and Infrastructure to Vehicle Communications

This section presents the operational concept for the Infrastructure System that supports the RSZW-LC application. The operational concept is presented from the perspective of each stakeholder group. References back to the original needs and challenges are noted in parentheses.

As a reference for this discussion, the VS09: Reduced Speed Zone Warning / Lane Closure service package from the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT), also known as the National ITS Architecture, has been tailored to support this ConOps. Figure 2 illustrates the tailored VS09 service package to visualize the interactions and perspectives presented below.
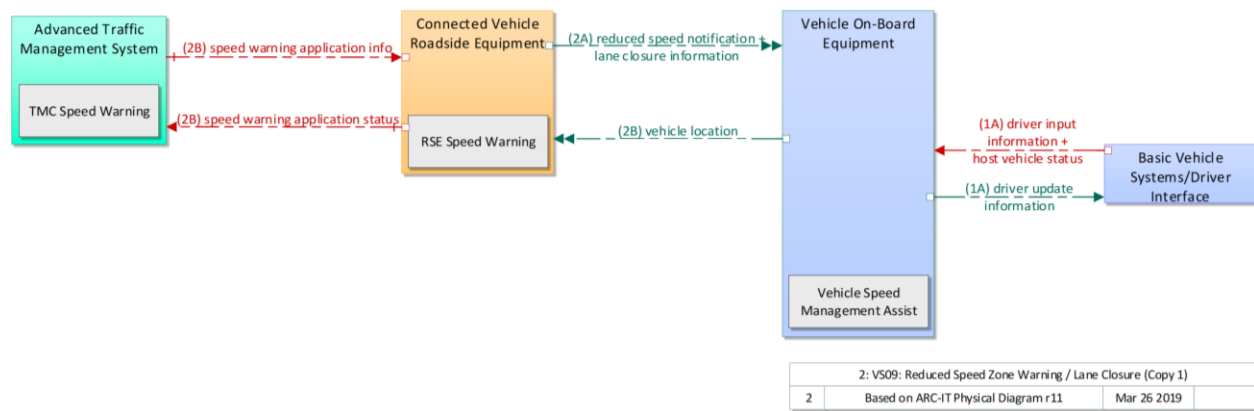

Figure 2 Service Package VS09 Reduced Speed Zone Warning / Lane Closure

The service package as presented in Figure 2 provides connected vehicles that are approaching a reduced speed zone with information on the zone's posted speed limit and/or if the configuration of the roadway is altered (e.g., lane closures, lane shifts). Reduced speed zones include (but are not be limited to) construction/work zones, school zones, and pedestrian crossing areas. The connected vehicle uses the revised speed limit along with any applicable changed roadside configuration information to determine whether to provide an alert or warning to the driver. It will provide an alert to drivers in advance when aggressive braking is required to reduce to the posted speed limit.

When considering the perspectives presented below, Figure 2 can be used as a reference by the reader to gain more insight.

This section is a primary source for developing functional requirements. Paragraphs are numbered to allow each developed requirement to reference the operational concept that is the source of the requirement.

3.1 Driver Perspective

3.1.1 Drivers will **not visually or audibly receive any direct communications from the Infrastructure System that supports the RSZW-LC application.** All V2I communications will occur between the Infrastructure System and the Vehicle Systems. Therefore, no operational concepts are described

in this document for drivers or riders in AVs, rather they would be described by the agencies and organizations that create the Vehicle Systems and in-vehicle applications.

3.2 Vehicle System Perspective

3.2.1 Vehicle Systems will have wireless data exchange with the Infrastructure System that supports the RSZW-LC application using 5.9 GHz DSRC communications, cellular communications, or some other communications mechanism. Vehicle Systems can receive notice of the situation impacting the downstream zone with changed lane configuration and/or reduced speed (hereafter referred to as "Zones") well in advance of the Zone, so low latency communications mechanisms are not as critical as they are when supporting other V2I applications.

3.2.2 Vehicle Systems will receive current, secure data from the Infrastructure System in order to support the RSZW-LC application for the Zone. **(Need 1.1, 3.1)**

3.2.2.1 Data received for Zones with a reduced speed would vary based on the deployment location. The primary data would be: 1) Begin location of the reduced speed zone; and 2) Posted speed limit through the reduced speed zone. Additional data for a reduced speed zone might include, as applicable: 3) End location of the reduced speed zone; 4) Time of day restrictions, e.g., school zones often have reduced speeds by time of day or a reduced speed limit that applies only at night; 5) Other conditions, e.g., a variable speed limit zone that uses dynamic signage, the reduced speed applies only to trucks, or the reduced speed only applies when workers are present; and 6) Active of flashing beacons or dynamic signage that is being used to indicate aforementioned speed restrictions and conditions.

3.2.2.2 Data received for Zones with a lane closure would vary based on the deployment location. The primary data would be: 1) Begin location of the lane closure, which may correspond to the begin location of the reduced speed zone; and 2) Lane that is closed, i.e., right, left, or center. Additional data for a lane closure might include, as applicable: 3) Number of lanes closed; 4) End location of the lane closure, which may correspond to the end location of the reduced speed zone.

3.2.2.3 Given the location of the proposed Infrastructure System within a work zone to provide lane closure and reduced speed data, additional data may be provided about current conditions as presented on static and dynamic roadside signage within the Zone that are not needed to support the RSZW-LC application.

3.2.3 Communications between the Infrastructure System and the Vehicle System is supported by Roadside Safety Message (RSM)[ii] using the structure of data elements / frames defined in the SAE

[ii] The Connected Vehicle Pooled Fund Study (CV-PFS), in cooperation with CAMP, is developing content for a Road Safety Message (RSM) to replace the Basic Information Message (BIM), and this content will be offered as input to the eventual RSM standard expected to be developed by SAE.

J2735 standard. Additional data elements and required structure for RSM currently not supported in the SAE J2735 are being proposed through SAE J2945/4. **(Need 1.1, 3.1)**

3.2.3.1 Vehicle Systems will receive data regarding the *current status* of the Zone in a RSM, including posted speed limit, closures, and, as necessary, workers present. **(Need 3.3)**

    3.2.3.1.1 Vehicle Systems will receive RSMs in a standardized format to describe the current status of the Zone. The consistency and standardization will enable vehicles to receive current speed and lane configuration data in the same consistent manner from any Zone broadcasting the information, even though the type of data provided will vary by location. **(Need 8.1)**

    3.2.3.1.2 Vehicle Systems will receive RSMs with different types of data depending on the location and nature of the Zone, e.g., RSMs provided for a school zone would not require data elements for current status regarding worker presence or lane closures.

3.2.3.2 The Vehicle Systems will receive *location data* from the Infrastructure System about the Zone and approach geometry, as necessary, that can be used to reference areas with reduced speeds, lane configuration changes, and worker presence that support the RSZW-LC application. This location data may include geospatial descriptions of node points in advance of and through each Zone by lane in order to enable the Vehicle System to relate the vehicle's position to the lanes, possible maneuvers, and appropriate speed using on-board GNSS data. **(Need 3.2)**

    3.2.3.2.1 Vehicle Systems will receive location data in a format that is standardized such that the Vehicle System can expect the same format from any Zone that is operating an Infrastructure System that supports the RSZW-LC application. The Zone location data may be communicated from the Infrastructure System to the Vehicle System as either high- or low-fidelity map data in the SAE J2945/4 (WIP) RSM Message. **(Need 8.1)**

    3.2.3.2.2 Location data will be updated when the Zone geometry or lane control changes. Changes to speed restrictions or worker activity will require changes to the RSM. In situations where geometry or lane control approaches change by time of day/day of week (e.g. a reduced speed zone for a school) the Infrastructure System that supports the RSZW-LC application will accommodate these dynamic changes. **(NTCIP 1202 and SAE J2735)**

    3.2.3.2.3 Vehicle Systems will receive current Zone location data that is accurate enough to enable the vehicle to compare the current vehicle position and direction to coordinates in the location data and determine the distance to the Zone and, if necessary, lane of travel. **(Need 8.3, 8.4)**

3.2.3.2.4 Vehicle Systems will receive location data frequent enough and current enough such that the data can be processed and compared with current vehicle position in time to present information to the drivers in advance of the Zone, regarding the need to reduce speed and/or safely merge from a lane that is closed downstream. **(Need 8.2)**

3.2.3.3 As needed, Vehicle Systems will rely upon <u>vehicle position correction data</u> communicated by the Infrastructure System to enable the vehicle to correct the GPS position determined by the vehicle. This will be needed in locations where atmospheric conditions cause localized delays in data transmitted from the GPS satellites and create local inaccuracies in GPS calculations, since on-board GPS devices function by receiving precisely timed transmissions from GPS satellites in order to calculate absolute position. (Need 3.4, 8.5)

3.2.3.3.1 Vehicle Systems will receive vehicle position corrections from every Zone broadcasting corrections. (Need 8.1)

3.2.3.4 Vehicle Systems will receive <u>security credentials</u> attached to messages in the form of digital signatures such that vehicles can validate that the message is authentic and secure. Vehicles will not accept RSZW-LC related messages sent to the vehicle unless the messages are digitally signed. **(Need 7.1)**

3.2.3.5 Vehicle Systems will receive available data from the Infrastructure System regardless of the lane they are in when approaching the Zone. **(Need 3.1)**

3.2.3.6 Vehicle Systems will receive messages frequently enough to perform near real-time calculations and determine messages to display to drivers. **(Need 8.2)**

3.2.4 Vehicle Systems may use the data received for the display of in-vehicle messages in the Zone. The receipt of data by the Vehicle System does not imply that the Vehicle System will generate a corresponding in-vehicle message to the driver.

3.2.4.1 Different Vehicle Systems may be equipped with different CV applications for the display of different types of in-vehicle messages or may choose not to act on data that is provided by the proposed Infrastructure System.

3.2.4.2 The Infrastructure Systems will not provide thresholds or sign graphics for the provision of any in-vehicle messages.

3.2.4.3 Vehicle System determination and display of in-vehicle messages provided to the driver are expected to vary. For instance, the display of in-vehicle messages to drivers in some cases may be configured based on the vehicle-specific operating characteristics, e.g., the safe speed for a truck in a curve may be lower than that for a car.

3.2.5 Vehicle Systems will communicate data describing the vehicle trajectory and status to the Infrastructure System that supports the RSZW-LC application.

3.2.5.1 Vehicle Systems will communicate current vehicle data formatted as the standardized Basic Safety Message (BSM) that may be received by the Infrastructure System that supports the RSZW-LC application (or any other system configured to receive BSM data). (Need 3.7, 6.2)

3.2.5.2 Vehicle Systems may communicate Probe Vehicle Data (PVD) that may be received by the Infrastructure System that supports the RSZW-LC application. (Need 3.7, 6.2)

3.2.5.3 *In situations where Vehicle Systems communicate data to Infrastructure Systems that support the RSZW-LC application, they will send messages that meet minimum credentialing requirements. (Need 7.3)*

3.3   Work Zone Operator and Traffic Engineer Perspective

3.3.1   Work zone operators or traffic engineers will assemble the data necessary to support the RSZW-LC application. IOOs may provide additional data in the RSM as it relates to MUTCD signage such that Vehicle Systems are enabled to determine and display messages. *(Need 3.5, 3.6)*

3.3.1.1 Data provided for Zones with a reduced speed would vary based on the deployment location, but would directly relate to what is currently provided on MUTCD-compatible static and dynamic roadside signage. The primary data would be: 1) Begin location of the reduced speed zone; and 2) Posted speed limit through the reduced speed zone. Additional information an IOO could provide in a RSM for a reduced speed zone might include, as applicable: 3) End location of the reduced speed zone; 4) Time of day restrictions, e.g., school zones often have reduced speeds by time of day or a reduced speed limit that applies only at night; 5) Other conditions, e.g., a variable speed limit zone that uses dynamic signage, the reduced speed applies only to trucks, or the reduced speed only applies when workers are present; and 6) Active of flashing beacons or dynamic signage that is being used to indicate aforementioned speed restrictions and conditions.

3.3.1.2 Data provided for Zones with a lane closure would vary based on the deployment location. The primary data would be: 1) Begin location of the lane closure, which may correspond to the begin location of the reduced speed zone; and 2) Lane that is closed, i.e., right, left, or center. Supplemental information an IOO may provide in a RSM for a lane closure might include, as applicable: 3) Number of lanes closed; 4) End location of the lane closure, which may correspond to the end location of the reduced speed zone.

3.3.1.3 Given the proximity of the proposed Infrastructure System to work zones in order to provide lane closure and reduced speed data, IOOs may choose to provide additional information in the RSM that would exceed the requirements of the RSZW-LC application and might be used for other purposes. For example, IOOs may find value in providing supplemental data that could be used to enhance safety and mobility via other safety applications for travelers or an application deployed on agency fleet vehicles.

3.3.1.4 Work zone operators or traffic engineers will provide oversight on location data for each Zone, which may be generated by a Surveyor or Mapper at the agency, a construction contractor responsible for the Zone, or a map provider. **(Need 4.1, 4.3)**

3.3.1.4.1 Work zone operators or traffic engineers will be responsible for making sure the location data is updated whenever the Zone geometry or lane control changes. Changes to speed restrictions or worker activity will require changes to the RSM. In situations where approaches change by time of day/day of week (e.g. a reduced speed zone for a school) the Infrastructure System that supports the RSZW-LC application will accommodate these dynamic changes. **(NTCIP 1202 and SAE J2735)**

3.3.2 Work zone operators or traffic engineers may use the user interface to interact with the Infrastructure System that supports the RSZW-LC application to configure the message to be communicated to the Vehicle System. **(Need 4.3)**

3.3.2.1 Work zone operators or traffic engineers will be responsible for providing power, communications, and other necessary utilities and services to the Infrastructure System so that it can be operated reliably and consistently. **(Need 8.2)**

3.3.2.2 The provision of data by the IOO to the Vehicle System via the Infrastructure System does not guarantee that the Vehicle System will provide a corresponding in-vehicle message to the driver. As such, IOOs should not expect the Vehicle Systems to replicate or replace the static and dynamic roadside signs and should not alter the use of static or dynamic signs in accordance with MUTCD guidelines.

3.3.2.3 IOOs are not responsible for the determination and display of in-vehicle messages by the Vehicle System.

3.3.2.4 IOOs will not provide thresholds or sign graphics in the RSM for the provision of any in-vehicle messages. IOOs are not responsible for how Vehicle Systems provide in-vehicle messages to drivers. Vehicle Systems will be equipped with the thresholds and processing capabilities that are necessary for determining the appropriate provision of alerts to drivers, as needed based on the type and severity of information.

3.3.2.5 IOOs will be able to configure the number of messages broadcast per second.

3.3.3 Work zone operators or traffic engineers will use a user interface to interact with the ITS and Traffic Control System to configure any data to be communicated from the ITS and Traffic Control System to the Infrastructure System that supports the RSZW-LC application, if additional data from the ITS and Traffic Control System will be provided from the Zone. **(Need 4.3)**

3.3.4 Work zone operators or traffic engineers will use the user interface to interact with the Infrastructure System that supports the RSZW-LC application to monitor the data being communicated by the system. **(Need 4.4)**

3.3.5 Work zone operators or traffic engineers will use the user interface to configure the Security Back-End System, including connections to one or more Security Credentialing Systems. **(Need 7.5)**

3.4   Surveyor and Mapper Perspective

3.4.1   Surveyors and Mappers may work for the IOO, construction contractor responsible for the Zone, or a map provider. These stakeholders will generate location data for a work zone or other reduced speed zone for the Infrastructure System to provide location information for each Zone. For example, in a work zone this will typically be the creation of a file that contains the location data for each Zone. **(Need 4.1, 4.3)**

3.4.2   Surveyors and Mappers will generate location data in a format that is standardized such that a Vehicle System can expect the same format from any Zone that is operating an Infrastructure System supporting the RSZW-LC application. Two scenarios exist for providing Zone location data using the SAE J2945/4 (WIP) RSM Message. **(Need 8.1)**

   3.4.2.1   _High-fidelity work zone map data._ When the IOO has sufficient resources, detailed lane specific data describing each lane through the Zone could be assembled according to the J2945/4 (WIP) RSM map message. This data contains details of the trajectories of open lanes, and would need to be accompanied by the detailed map node attributes defined in the RSM to describe the change in lane configuration within a lane and / or workers presence zone status in work zone.

   3.4.2.2   _Low-fidelity work zone map data_. When the IOO does not have the resources to assemble the map data, Zone descriptions may be conveyed as a stand-alone low-fidelity message in RSM. In these situations, the Zone map data will be higher level (e.g. not lane specific) but will still be intended to meet the needs of the Vehicle System.

3.4.3   The SAE J2945/4 (WIP) RSM focuses on information about lanes. For the purposes of applications using DSRC, it would typically contain the lane information for a single event, including the change in lane configuration, allowable speed limit and geometric description or pathway of available lanes.

   3.4.3.1   The Zone (the area where vehicles are approaching and traveling through the work zone or speed reduction) would have a unique event integer ID within a unique road regulator ID.   This will help the on-board applications receiving the information to manage information from multiple zones.

   3.4.3.2   The reference point for work zones will be captured and recorded as the start of the work zone where lane closure or speed reduction is effective.

      3.4.3.2.1   Each lane will be described by node points along the center of the lanes. The node points extend in both directions (upstream and downstream) from the reference point, starting with a node at the Reference Point and ending upstream with a node as far back from the start of the zone approach as is needed for the RSZW-LC enabled application to function properly. Downstream, the nodes extend as a distance beyond the end of the zone (i.e. at a point where all lanes are open and operating at posted speeds).

3.4.3.2.2 The upstream and downstream nodes from the reference point are defined by their latitude/longitude/altitude and appropriate attributes.

3.4.3.2.3 Within the work zone or location of speed reduction, nodes may only include for the open section of lanes (i.e. in a three-lane freeway with two lanes closed, nodes would describe the one open lane through the work zone). *See Figure 3 and Figure 4 describing different scenarios.*

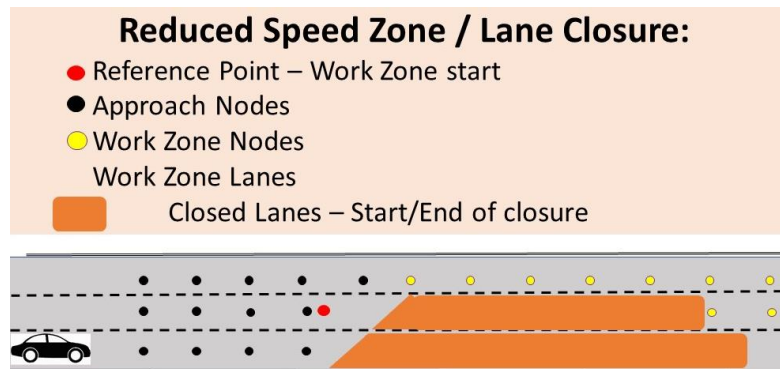

Figure 3. Illustration of nodes used in RSM map Data
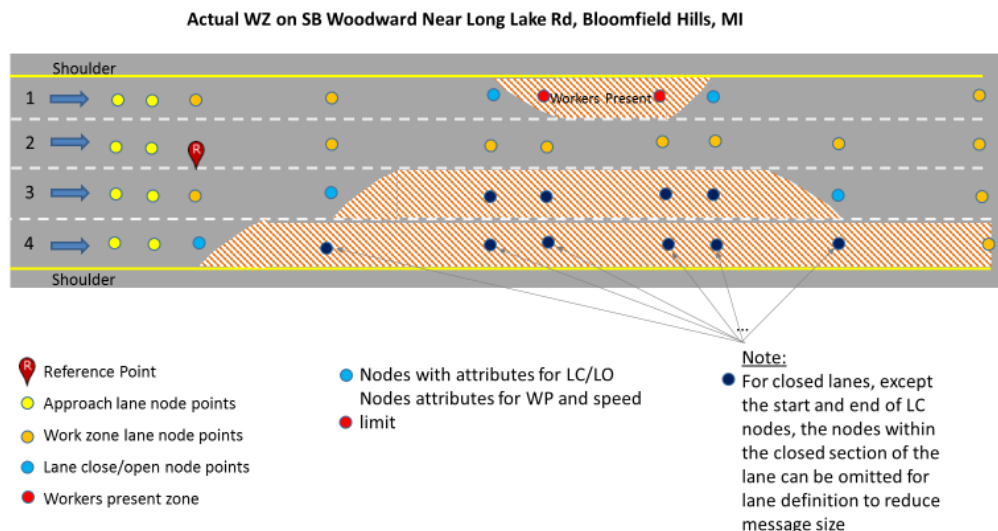

Figure 4. Example illustration of nodes in RSM WZ map Data

3.4.3.2.4 Nodes with additional attributes will identify the geometry of the taper from the point where the lane taper begins to end the lane to the lane the vehicles would merge to, indicating the safe merge from open to closed lanes.

3.4.3.2.5 On-board applications assume the lane is a straight line connecting the node points. Therefore, zones occurring along areas of curved roads would require a higher density of node points than those along straight roadway stretches.

3.4.3.2.6 A curved approach lane would need sufficient nodes such that straight lines connecting the nodes do not deviate from the actual center line of the lane by more than one-half the width of the lane. See Figure 5.
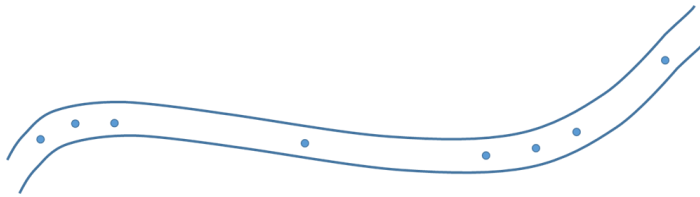

Figure 5. Example illustration of node placement for curved and straight sections in RSM WZ map Data

3.4.4   Surveyors and Mappers may provide this location data to work zone operators or traffic engineers, for a work zone or other reduced speed zone respectively, or directly use the user interface to the Infrastructure System. The generated location data will support the RSZW-LC application for each Zone. **(Need 4.1, 4.3)**

3.5   Maintenance Tech Perspective

3.5.1   Maintenance techs will perform troubleshooting and repairs to restore operations when any portion of the Infrastructure System that supports the RSZW-LC application is not working.

3.5.1.1 Maintenance techs will receive alerts and reports indicating a malfunction. **(Need 5.1)**

3.5.1.2 Maintenance techs will view logs and reports to help diagnose malfunctions. **(Need 5.1)**

3.5.1.3 Maintenance techs will be able to reset hardware and software portions of the system and to update software and firmware. **(Need 5.2)**

3.5.1.4 Maintenance techs will be able to update the operating system or the firmware for all, some, or individual RSUs based on a defined schedule. **(Need 5.3)**

3.5.1.5 Maintenance techs will be able to configure many, multiple, or individual RSUs for field deployment through a management platform. **(Need 5.4)**

3.6   ITS and Traffic Control System Perspective

3.6.1   The ITS and Traffic Control System will provide speed, lane configuration and closure, worker presence, and other available data, as needed, to the Infrastructure System that supports the RSZW-LC application. **(Need 6.1)**

3.6.1.1 The ITS and Traffic Control Systems will output the data elements from the SAE J2735 Mar 2016 standard that support the RSZW-LC and related applications.

3.6.1.2 The ITS and Traffic Control Systems will generate messages containing the data using the approach defined in the SAE J2735 standard.

3.6.1.3 The ITS and Traffic Control Systems that are operating SAE J2735 standard will be able to output the mandatory and optional data needed to populate the data. **(NTCIP 1202)**

3.6.2   In locations with dynamic maps or data (i.e. maps change periodically such as a school zone speed limit that changes during specific hours of the day, days of the week, and weeks of the year) the ITS and Traffic Control Systems will output an indication of the status of these Zones such that the Vehicle System will be aware of the currently enabled lanes and/or associated speeds. Note: the configuration of which system produces the appropriate map is a local design decision, however the indication of the lane status is the role of the ITS and Traffic Control System. **(Need 6.1)**

3.6.3   The ITS and Traffic Control System may include an Advanced Traffic Management System (ATMS), located either on-site locally at the work zone or housed at a TMC connected to the Infrastructure System that supports the RSZW-LC application through backhaul communications.

*3.6.3.1 Connections to an ATMS are not mandatory for Infrastructure Systems that support the RSZW-LC application. Any ATMS interaction with Infrastructure Systems that support the RSZW-LC application will primarily be obtaining data collected by the Infrastructure System. **(Need 6.2)***

*3.6.3.2 If the ITS and Traffic Control System receives PVD or BSM data, the system might use the data to calculate queue length at the work zone, delay at the work zone, or to archive the data for future use. **(Need 6.2)***

3.6.3.3 Due to the potential for large amounts of data resulting from an increasing number of equipped Vehicle Systems broadcasting a BSM 10 times per second, the ITS and Traffic Control System may receive data from the Infrastructure System that supports the RSZW-LC application that the Infrastructure System has aggregated or processed before sending it to the ITS and Traffic Control System.

3.7   Security Back End Perspective

3.7.1   A Security Back End System will operate within the agency responsible for the Zone, within a partner agency, by the construction contractor, or be a commercially-provided service. The Security Back End System will either be, or be compatible with, a National Security Credentials Management System (SCMS) to enable it to issue digital signatures and verify the credentials of digitally-signed messages. The security credentials used to digitally sign the messages are normally supported by a SCMS at a remote location accessible over the Internet. The Security Back End System will typically be connected through backhaul communications to each Infrastructure System. A wide range of communications approaches, from cellular data to a cable or phone company Internet drop to an agency-owned fiber optic communications system would all be options for this connection. Additionally, the Security Back End System will include any agency network configuration or monitoring equipment supporting network security of the Infrastructure System that supports the RSZW-LC application and backhaul communications system.

3.7.1.1 The Security Back End System will interact with the Infrastructure System to enable the Infrastructure System to verify if messages received from Vehicle Systems are digitally signed with current credentials. **(Need 7.3)**

3.7.1.1.1 The Security Back End System may communicate to the Infrastructure System the revoked security credentials to enable the Infrastructure System to process security credentials received from vehicles. **(Need 7.2)**

3.7.1.2 The Security Back End System will interact with the Infrastructure System to communicate security credentials to be attached to messages in the form of digital signatures such that vehicles can validate that the message is authentic and secure. Vehicles will not accept RSZW-LC related messages sent to the vehicle unless the messages are digitally signed. **(Need 7.1)**

3.7.1.3 The Infrastructure System will be enrolled in and maintain current security credential certifications required for the RSZW-LC or related applications supported at the location of the Infrastructure System (e.g. if the Infrastructure System is only broadcasting RSZW-LC related data and not receiving vehicle data, the Security Back End would not need to validate vehicle credentials). **(Need 7.1)**

4.   Infrastructure System Operational Scenario

This scenario illustrates the expected operation of an Infrastructure System that supports the RSZW-LC application communicating to vehicles using DSRC, C-V2X, cloud-based communications, or a combination of these mechanisms that utilize RSMs, and also interface with local ITS and Traffic Control Systems.

4.1   Initial Conditions

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

The Vehicle System:

- Is approaching the Zone with changed lane configurations and/or reduced speeds.

- Continuously knows its current position.

- Is configured to receive RSM, including supporting standard message security features.

- Is configured with enabled RSZW-LC and related applications to support the driver.

- Is configured to receive position correction information and to apply it to its current position, as needed to support enabled applications.

The ITS and Traffic Control System:

- Is operating normally, with no failure mode flashing operation in effect.

- Has been configured and is sending data to the Infrastructure System that supports the RSZW-LC application, as needed, which could include overall status information regarding speed or presence of workers, for example.

The Infrastructure System that supports the RSZW-LC application:

- Is configured with current, timely, and accurate information regarding current Zone conditions, location, and/or restrictions that are required for supporting the RSZW-LC application, at a minimum.

- Is configured and broadcasting proper messages (i.e. RSMs). This scenario is written to describe a sequence of events using local, short-range communications, such as DSRC or C-V2X, and may differ for other communications mechanisms.

- Is configured and is receiving supporting data from ITS and Traffic Control Systems, as well as Vehicle Systems, as necessary.

- Supports standard message security features.

4.2   Sequence of Events

1. The Vehicle System receives an RSM from the Infrastructure System and validates the security credentials.

2. The Vehicle System decodes the RSM and determines:

    a. Zone location and available approach information for the Zone

    b. Available lane segment location, restrictions or closures, current allowable speeds, and adjacent worker presence, as necessary.

3. The Vehicle System may receive position correction information and use it to more accurately determine its current position.

4. Based upon its current location, the Vehicle System determines which lane it is in if a lane restriction or closure is in effect.

5. Based upon which lane it is in, lane restrictions or closures that are in effect, current speed, and driver actions regarding speed, the Vehicle System generates appropriate alert messages to the driver via the in-vehicle RSZW-LC application.

6. The Vehicle System broadcasts a BSM that is received by the Infrastructure System.