Vehicle-to-Infrastructure (V2I) Safety Applications

Concept of Operations Document

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16. Abstract

This document describes the Concept of Operations (ConOps) for five connected vehicle vehicle-to-infrastructure (V2I) safety applications, and the underlying connected vehicle system, for crash avoidance for the U.S. Department of Transportation (USDOT). The ConOps describes the current state of roadway safety operations across the country with respect to intersection safety, rail crossing safety, weather impacts, oversize safety, and work/speed zones; establishes the reasons for change; and describes the selected connected vehicle V2I safety applications in terms of their features and operations by:

- Capturing and documenting user needs as they relate to connected vehicle V2I safety applications; and
- Describing the safety applications and connected vehicle system functions in non-technical language from the user's point of view.

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-	8/10/2012	Initial Draft Release	
A	11/9/2012	Incorporate Walkthrough review comments	Entire Document
B	3/8/2013	Revisions based on AAR comments for RCVW application	Sections 1, 5-6, and 8 pertaining to RCVW application
C	3/26/2013	Added source information to cover photos	Back of cover page

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Executive Summary

This document describes the Concept of Operations (ConOps) for five connected vehicle vehicle-to-infrastructure (V2I) safety applications, and the underlying connected vehicle system, for crash avoidance for the U.S. Department of Transportation (USDOT). The ConOps describes the current state of roadway safety operations across the country with respect to intersection safety, rail crossing safety, weather impacts, oversize safety, and work/speed zones; establishes the reasons for change; and describes the selected connected vehicle V2I safety applications in terms of their features and operations by:

- Capturing and documenting user needs as they relate to connected vehicle V2I safety applications; and
- Describing the safety applications and connected vehicle system functions in non-technical language from the user's point of view.

In general, a ConOps is intended to be a user-oriented document that describes system characteristics for a proposed system from the users' (e.g., vehicle owner/operator) viewpoint. The ConOps document is used to communicate the overall quantitative and qualitative system characteristics to the user, buyer, and developer, and to document other organizational elements (e.g. training, facilities, staffing and maintenance). It is used to describe the user organizations, missions, and organizational objectives from an integrated systems point of view. As such, the descriptions of user needs and functionality in this document are direct inputs into the process of capturing specific and verifiable engineering requirements as well as the design and testing of these applications.

This document describes the ConOps for five connected vehicle V2I safety applications related to intersection and roadway safety; these applications are described in more detail below and include:

- *Stop Sign Violation Warning (SSVW)* – Application designed to warn drivers that they may violate an upcoming stop sign based on their speeds and distance to the stop sign.
- *Railroad Crossing Violation Warning (RCVW)* – Application designed to warn drivers of the need to stop for crossing or approaching trains at an at-grade rail crossing.
- *Spot Weather Information Warning (SWIW)* – Application designed to use standalone weather systems to warn drivers about inclement weather conditions (i.e., fog, wind, adverse surface conditions, etc.) that may impact travel conditions.
- *Oversize Vehicle Warning (OVW)* – Application designed to provide warning to drivers of oversize vehicles (overheight/overlength/overwidth) for restricted clearances (e.g., tunnel and/or bridge clearances) ahead.
- *Reduced Speed Zone Warning (RSZW)* – Application designed to warn drivers of excessive speeds compared with the posted speed limit in reduced speed zones and changed roadway configurations. Reduced speed zones may include school zones, work zones, and populated areas.

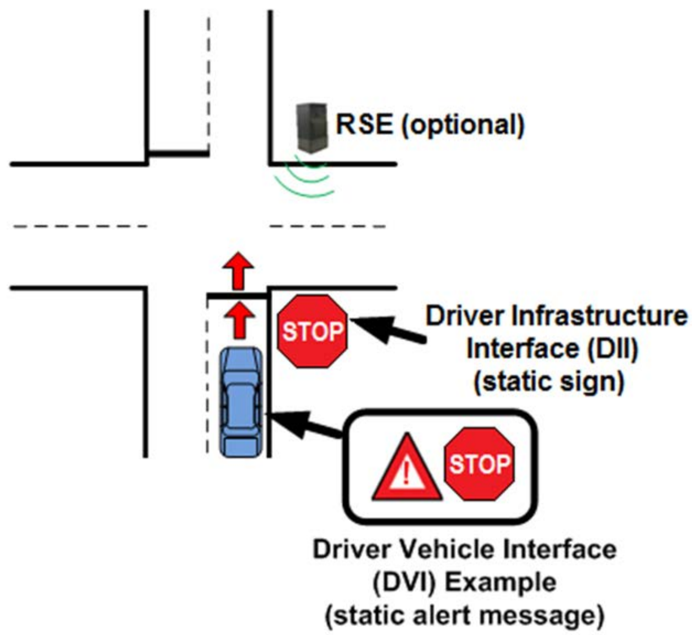
Presently, many infrastructure-based countermeasures or vehicle-autonomous systems have been implemented by public agencies and vehicle OEMs for the purpose of improving safety. These systems, until recently, have not typically integrated these two environments. Integrating data and systems for both roadside infrastructure and the vehicle can provide a richer information set for identifying driving hazards and providing more accurate and timely warnings to drivers of unsafe conditions at an intersection. Connected vehicle systems have the advantage of collecting and sharing real-time data and warnings that are more likely to capture the attention of drivers due to their dynamic nature and improved reliability over static warning signs. As previously discussed, the purpose of this document is to develop the ConOps for five applications that either create new or expand existing safety improvement over the current practice by integrating these infrastructure and vehicle-based technologies.

These safety applications are sub-components of the larger connected vehicle program, which will produce other ConOps documents related to safety, mobility, and the environment. The safety applications in this document complement three V2I safety applications: Red-Light Violation Warning (RLVW), Stop Sign Gap Assist (SSGA), and Curve Speed Warning (CSW), which were presented in an earlier ConOps document from this project (FHWA-JPO-13-058). Other ConOps relevant to the larger USDOT connected vehicle program include those being developed by USDOT for the Smart Roadside Initiative, Signal Phase and Timing (SPaT) and Other Related Messages, Transit Connected Vehicles, and more recently the connected vehicle railroad program. Copies of the published versions of these other supporting ConOps are included as Appendices to this document. This ConOps is limited to describing the expected functionality, operation, and rationale for existence of the five safety applications listed above.

Following is a brief description and graphical illustration of each of the five applications described in more detail in this ConOps.

Stop Sign Violation Warning (SSVW)

The objective of SSVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at intersections by warning the vehicle driver that a stop sign violation is predicted to occur. An equipped vehicle approaching an equipped intersection receives messages about the intersection geometry and if necessary, position correction information. The driver is issued a warning if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to violate the stop sign. Figure ES-1 illustrates the proposed SSVW application design.



Source: Battelle

Figure ES-1. SSVW Illustration

Railroad Crossing Violation Warning (RCVW)

The objective of RCVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at railroad crossings by warning the vehicle driver that a crash-imminent situation with a crossing or approaching train is predicted to occur. An equipped vehicle approaching an equipped crossing receives messages about the intersection geometry, presence of an approaching or crossing train, and if necessary, position correction information (e.g., lane level accuracy may be required for some situations, such as when a vehicle on an adjacent parallel roadway approach an intersection in a turn lane to turn toward the direction of an at-grade railroad crossing with a present or approaching train). The driver is issued a warning if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to enter a crash-imminent situation with the approaching or crossing train. Figure ES-2 illustrates the proposed RCVW application design.

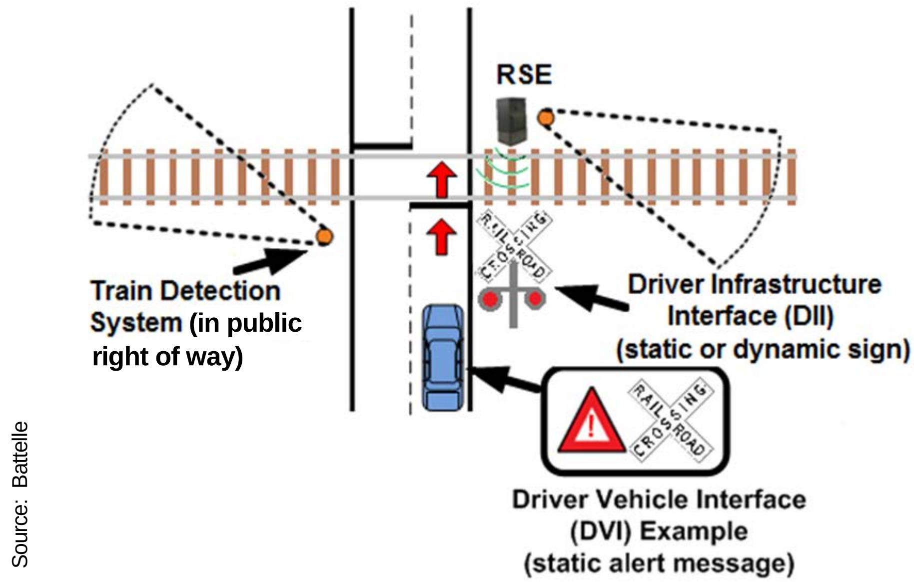


Figure ES-2. RCVW Illustration

Spot Weather Information Warning (SWIW)

The objective of SWIW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes in areas prone to adverse weather impacts by warning the vehicle driver that a crash-imminent situation is possible, particularly in extreme situations where precautions are not taken, such as reducing speed or seeking an alternate route. The infrastructure application will collect available infrastructure and vehicle data, most importantly from RWIS and process available data to recommend an appropriate advisory message, alert, and/or warning. Depending upon the availability of data for validation (e.g., redundant RWIS data source, traffic speeds, etc.), validation of the recommended message may be needed from a back office traffic management center (TMC) before the message is posted on the DII. An equipped vehicle approaching an equipped roadway segment will receive a message that includes data regarding the message posted on DII; length of adverse weather impact zone [throughout which the driver-vehicle interface (DVI) message should apply]; weather data collected by RWIS; and, if available, the advisory, enforceable speed, and/or diversion to an alternate route as recommended by the infrastructure application. The driver is issued an advisory message, alert, or warning if the vehicle processing platform determines that, given current operating conditions, a crash-imminent situation is likely to occur due to the weather impacts, and notifies the driver if reduced speed or an alternate route is recommended. Figure ES-3 illustrates the proposed SWIW application design.

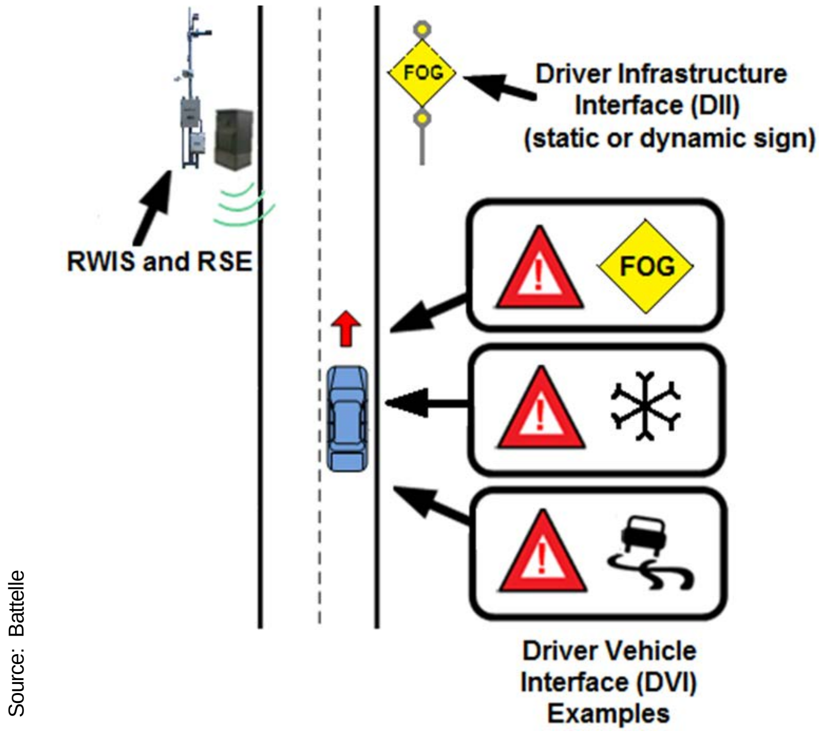


Figure ES-3. SWIW Illustration

Oversize Vehicle Warning (OVW)

The goal of OVW is to provide a cooperative vehicle and infrastructure system that helps drivers of oversize vehicles avoid collisions with roadway clearance obstacles by alerting and/or a warning the driver as they approach the roadway clearance obstacle. An equipped vehicle on a stretch of road ahead of a roadway clearance obstacle (e.g., low- or narrow clearance bridge or tunnel) is issued an alert (and if necessary a warning) if the vehicle application determines that, given the current height and width of the vehicle (as measured by the roadside infrastructure), the driver will not clear the obstacle. While this application will be commonly used by commercial motor vehicles (CMVs), it applies to all oversize vehicles (e.g., recreational vehicles [RVs]). Figure ES-4 illustrates the proposed OVW application design.

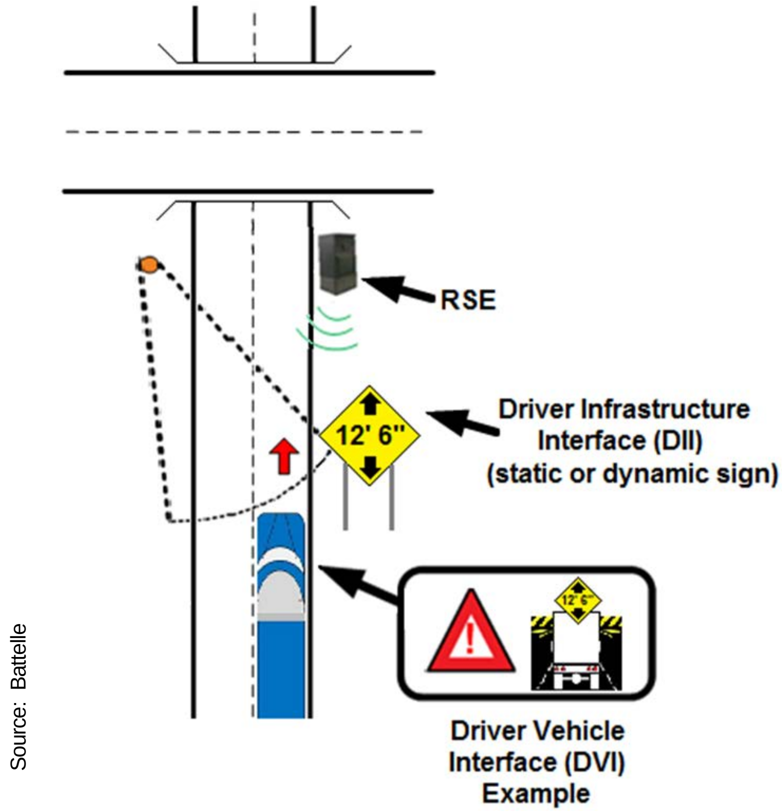


Figure ES-4. OVW Illustration

Reduced Speed/Work Zone Warning (RSZW)

The objective of the RSZW is to provide a cooperative vehicle and infrastructure system that helps drivers avoid crashes in reduced speed zones by warning the driver that they are operating at a speed higher than the zone's posted speed limit and/or providing information regarding changes in roadway configuration (e.g., lane closures, lane shifts), particularly for a crash imminent scenario requiring a lane change. An equipped vehicle on a stretch of road ahead of a reduced speed zone is issued an alert (and if necessary a warning) if the vehicle application determines that, given the current vehicle speed and approaching reduced speed zone roadway configuration (as provided by the roadside infrastructure), the driver is at risk of an incident based on his or her current speed or changes in the roadway. Similarly, an unequipped vehicle is issued an alert (and if necessary a warning) if the infrastructure application determines that, given the current vehicle speed and approaching reduced speed zone roadway configuration, the driver is at risk of an incident. Figure ES-5 summarizes the proposed RSZW application design.

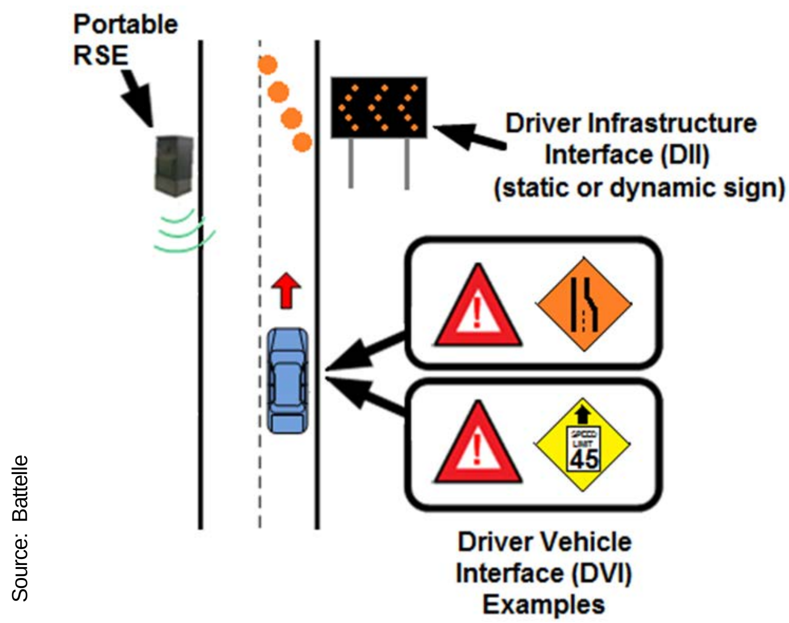


Figure ES-5. RSZW Illustration

The most significant operational impact of these applications is their effect on increased roadway safety. Expected benefits include:

- Reductions in the number of roadway fatalities
- Reductions in the number and severity of roadway injuries
- Reductions in property damage associated with roadway incidents
- Reductions in the number of near-miss intersection conflict and run-off-road (ROR) incident scenarios.

Additional benefits may include:

- The development of a safety warning system that is deployable nationwide and found to be acceptable, understood, and useful to users, so as to elicit timely and appropriate driver response
- The development of a connected vehicle environment in which emerging technologies can utilize existing infrastructure to enhance safety benefits (eventually incorporating V2V concepts)
- The deployment of technology systems to establish a foundation of communication and technologies that will bridge the gap between current roadway safety conditions with non-equipped vehicles and a saturated connected vehicle environment
- Continued promotion of the institutional relationship between the public (e.g., U.S., state, and local DOTs) and private sectors (e.g., vehicle manufacturers) to further promote transportation safety.

The ConOps includes the following key descriptions and discussions pertinent to V2I safety applications for intersection and roadway safety:

- Section 3 (Current System or Situation) describes the current situation regarding vehicle safety with respect to warning drivers of potential hazards related to intersection collision avoidance; railroad crossing collision avoidance; weather impacts; vehicle clearances; and speed on rural, suburban, and urban roadways including work zone areas.
- Section 4 (Justification for and Nature of Changes) describes deficiencies of the existing situation and the benefits of change.
- Section 5 (Concept for the Proposed System) describes the proposed system that will result from the desired changes. This is, necessarily, a high-level description, indicating the operational features of the demonstration system when deployed.
- Section 6 (Operational Scenarios) contains operational scenarios for the system. A scenario is a step-by-step description of how the proposed system might operate and interact with its users and its external interfaces under a given set of circumstances. The scenarios tie together all parts of the proposed system, the users, and other entities.
- Section 7 (Summary of Impacts) describes the operational impacts of the proposed system on the users, the developers, the maintenance organizations, and the support organizations.
- Section 8 (Analysis of the Proposed System) describes the benefits, limitations, advantages, disadvantages, and trade-offs considered for the system.

1.0 Scope

This document describes the Concept of Operations (ConOps) for selected connected vehicle vehicle-to-infrastructure (V2I) safety applications, and the underlying connected vehicle system, for crash avoidance for the U.S. Department of Transportation (USDOT). The ConOps describes the current state of operations with respect to roadway vehicle safety across the country, establishes the reasons for change, and describes the selected connected vehicle V2I safety applications in terms of their features and operations.

The concept of connected vehicles was developed from intelligent highway vehicle programs including the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the Transportation Equity Act for the 21st Century (TEA-21) of 1997, and the Intelligent Vehicle Initiative (IVI) that was created through TEA-21. In broad terms, the connected vehicle program envisions a communications infrastructure that includes elements of vehicle-based communication units or onboard equipment (OBE), static roadside sensors and communications or roadside equipment (RSE), and the centralized network that manages the exchange of data. For the purpose of this ConOps, the connected vehicle system is considered the V2I data communications platform that supports numerous applications including those with safety objectives. Moreover, the intent here is that the vehicle and roadside communication link shall be compliant with the emerging USDOT enabling technologies, and the specifics of its performance requirements will vary by application and will be defined in that phase of the application.

The purpose of these safety applications is to provide more robust and reliable alerts and warnings to drivers on the roadside and in equipped vehicles. Connected vehicle systems have the advantage of collecting and sharing real-time data and warnings that are more likely to capture the attention of drivers due to their dynamic nature and improved reliability over static warning signs.

The goals of the connected vehicle V2I safety applications ConOps are to:

- Follow the guidance in the Institute of Electrical and Electronics Engineers (IEEE) Standard 1362-1998 in developing the ConOps
- Define the needs of users (e.g., drivers, original equipment manufacturers [OEMs], suppliers, and roadway operators) for the applications across all vehicle classes
- Describe concepts for connected vehicle safety applications that bridge the gap between user needs and visions and developers' technical specifications
- Depict quantitative and qualitative system characteristics of connected vehicle safety from the user and operator perspectives
- Address key USDOT application areas of interest:
    - Intersection safety (i.e., Cooperative Intersection Collision Avoidance Systems, or CICAS, as it pertains to stop sign violations)
    - Railroad crossing safety (i.e., railroad crossing violation warning)

- Weather impacts to traffic (e.g., caused by limited visibility, adverse surface conditions, flooding, or high winds)
- Oversize vehicle clearances (i.e., oversize vehicle warning)
- Speed management (i.e., reduced speed zone warning)
- Work zone safety (i.e., as a part of reduced speed zone warning)

- Create a comprehensive ConOps that is feasible for cost effective design, implementation, operations, and maintenance to accelerate the progress of improving safety via connected vehicle innovations and incremental deployment
- Provide a primary resource for development of system engineering requirements for
  - The connected vehicle system
  - Key connected vehicle V2I safety applications
- Make the ConOps available to connected vehicle stakeholders and organizations that are interested in further developing and implementing systems based on the connected vehicle safety concept.

This connected vehicle V2I safety applications program project is divided into three phases. Phase I consisted of establishing the baseline policies and procedures that guide the conduct of the program. Phase II consists of developing this ConOps document and Phase III will further develop these concepts into system requirements.

1.1 Document Identification

This document describes the ConOps for five connected vehicle V2I safety applications related to intersection and roadway safety. Specifically, these applications are:

- Stop Sign Violation Warning (SSVW)
- Railroad Crossing Violation Warning (RCVW)
- Spot Weather Information Warning (SWIW)
- Oversize Vehicle Warning (OVW)
- Reduced Speed Zone Warning (RSZW).

These safety applications are sub-components of the larger connected vehicle program, which will produce other ConOps documents related to safety, mobility, and the environment. This ConOps is limited to describing the expected functionality, operation, and rationale for existence of the five safety applications listed above. This document is, in part, derived from the Crash Avoidance Metrics Partnership (CAMP) CICAS limited to Stop Sign and Traffic Signal Violations (CICAS-V) research, and some of the content from associated documents is included here in its original or modified context for clarity and continuity.[1]

[1] For sources see section 2 "Referenced Documents."

1.2 Document Overview

The purpose of this ConOps is to:

- Capture and document user needs as they relate to connected vehicle V2I safety applications
- Describe the safety applications and connected vehicle system functions in non-technical language from the user's point of view.

The descriptions of user needs and functionality in this document are direct inputs into the process of capturing specific and verifiable engineering requirements as well as the design and testing of these applications.

The intended audience of this ConOps document includes: application developers; automotive, rail, commercial vehicle, motor coach, wireless, and intelligent transportation system (ITS) equipment OEMs; State and local DOTs; railroads and transit operators; and USDOT connected vehicle program managers who are managing the safety applications work.

The remainder of this document consists of the following sections and content:

Section 2 (Referenced Documents) describes the external documentation referenced throughout this document.

Section 3 (Current System or Situation) describes the current situation regarding vehicle safety with respect to warning drivers of potential hazards related to intersection collision avoidance; railroad crossing collision avoidance; weather impacts; vehicle clearances; and speed on rural, suburban, and urban roadways including work zone areas.

Section 4 (Justification for and Nature of Changes) describes deficiencies of the existing situation and the benefits of change.

Section 5 (Concept for the Proposed System) describes the proposed system that will result from the desired changes. This is, necessarily, a high-level description, indicating the operational features of the demonstration system when deployed.

Section 6 (Operational Scenarios) contains operational scenarios for the system. A scenario is a step-by-step description of how the proposed system might operate and interact with its users and its external interfaces under a given set of circumstances. The scenarios tie together all parts of the proposed system, the users, and other entities.

Section 7 (Summary of Impacts) describes the operational impacts of the proposed system on the users, the developers, the maintenance organizations, and the support organizations.

Section 8 (Analysis of the Proposed System) describes the benefits, limitations, advantages, disadvantages, and trade-offs considered for the system.

Section 9 (Notes) provides definitions for terms, acronyms, and abbreviations used throughout the document.

1.3 System Overview

This project is sponsored by the USDOT and has a goal of supporting the development and implementation of connected vehicle V2I safety applications. As part of this implementation, the USDOT identified priorities for V2I safety applications, which include intersection safety, railroad crossing safety, weather impacts, vehicle clearances, speed management, and work zone safety.

The general framework for the connected vehicle V2I safety applications is shown in Figure 1-1. As shown, it includes both Vehicle and Infrastructure (roadside) Application Platforms that house the roadside and vehicle components of the V2I safety applications respectively. This same figure also shows external inputs into the system. The Vehicle Application Platform captures sensor data through interfaces such as the Onboard Diagnostics (OBD2) network and Controller Area Network (CAN) for use by the applications. The Infrastructure Application Platform captures roadside data such as signal controller and road weather information for use by applications. Inclusion of infrastructure data equipment and infrastructure signage in the System of Interest (SOI) is dependent upon the specific application as well as the presence of existing signage. Note that the USDOT connected vehicle core system contains additional components for security and other purposes that are not represented in this diagram. Diagrams specific to individual safety applications are presented later in this document.

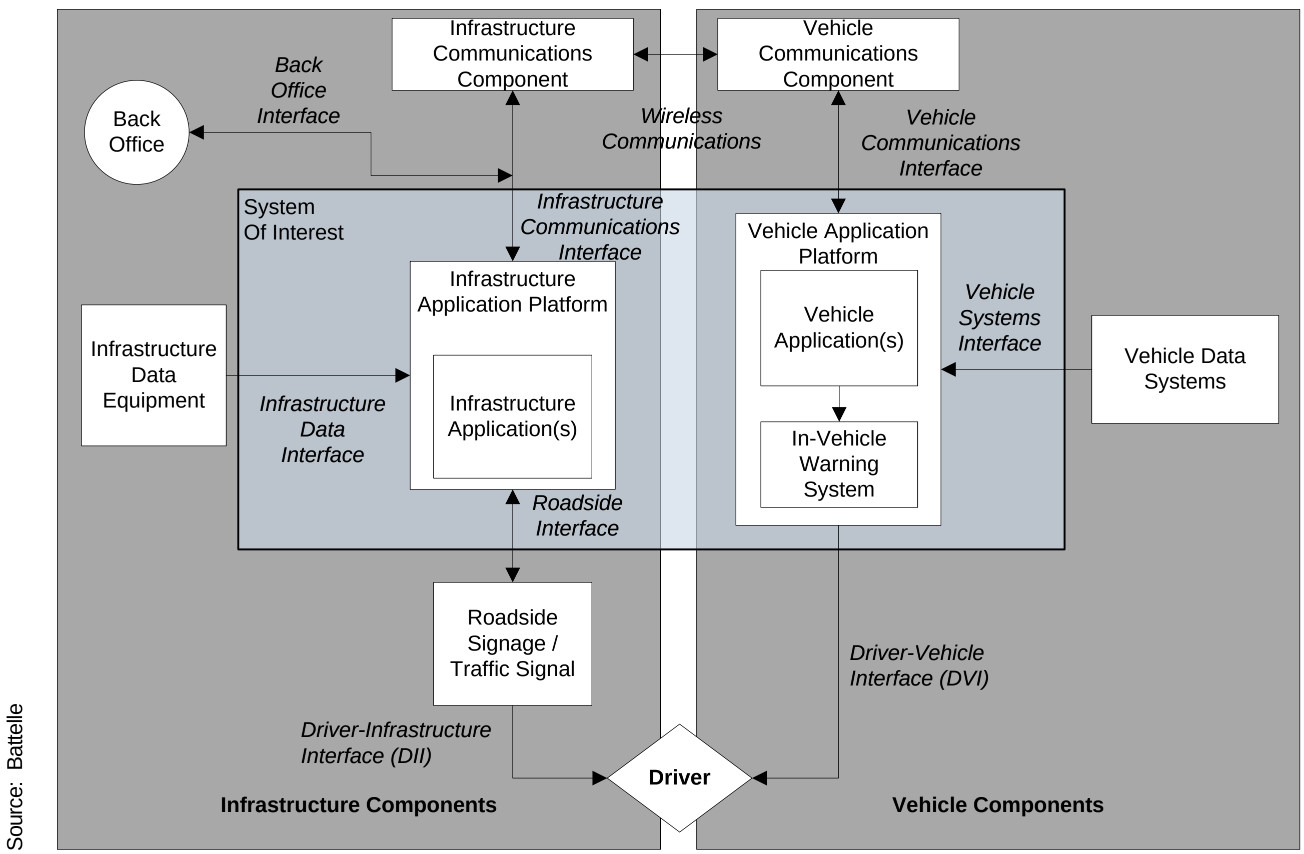
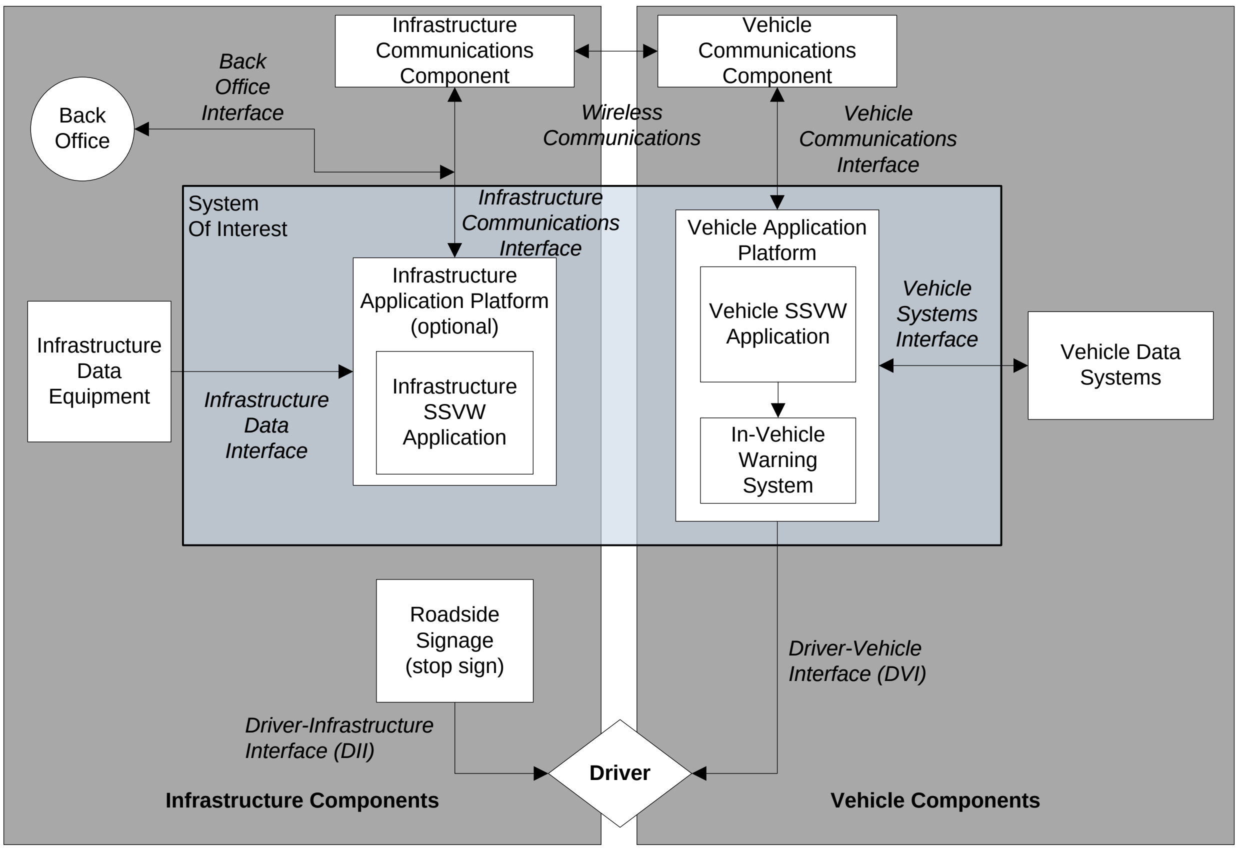


Figure 1-1. General Framework for Connected Vehicle V2I Safety Applications

1.3.1 System of Interest – Stop Sign Violation Warning (SSVW) Application

The SSVW safety application is intended to improve safety at stop-controlled intersections with posted stop signs. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, focusing mostly on onboard warning systems, to make drivers approaching a stop-controlled intersection aware of the need to stop ahead if a violation is predicted to occur. In this way, the SSVW application will help reduce the number of drivers that run stop signs, reducing the number of conflicts and crashes. Figure 1-2 summarizes the proposed SSVW application design.

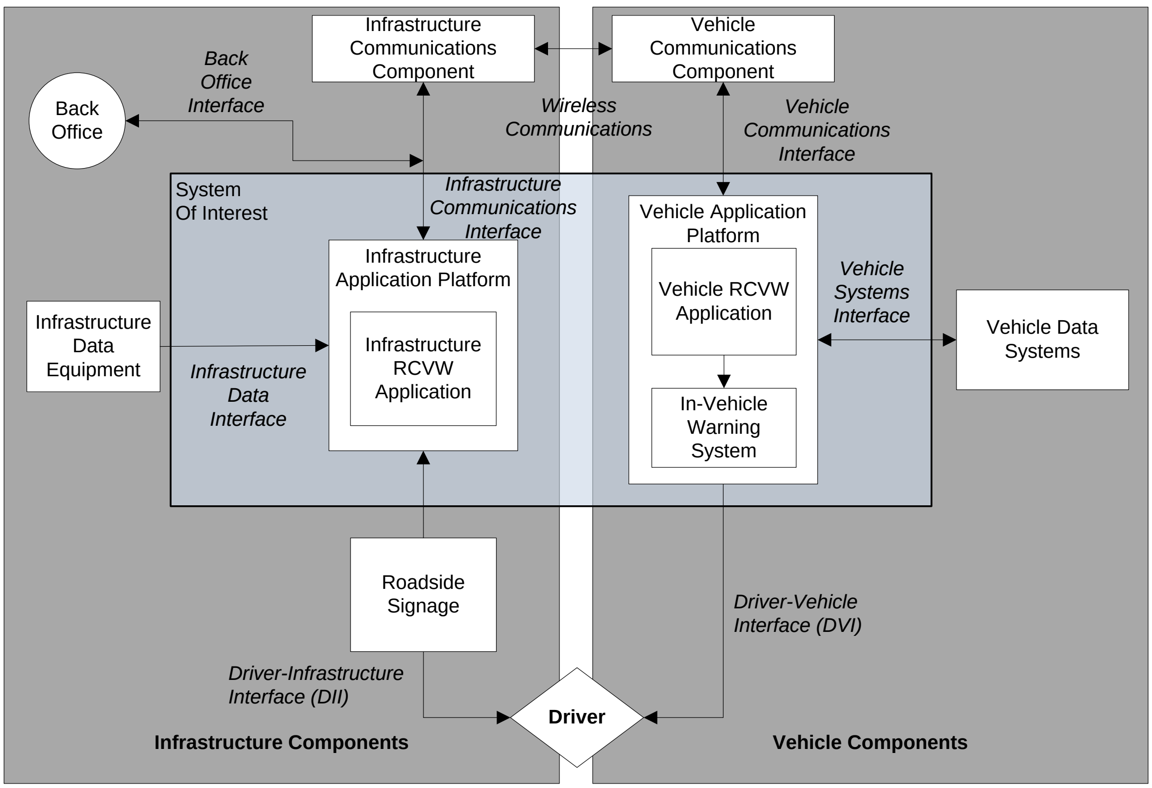


Source: Battelle

Figure 1-2. Stop Sign Violation Warning Application Diagram

1.3.2 System of Interest – Railroad Crossing Violation Warning (RCVW) Application

The RCVW safety application is intended to improve the safety of at-grade railroad crossings, regardless of whether the roadside signage is static or a dynamic signal warning system. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, focusing mostly on onboard warning systems, either with or without additional data from the railroad, to make drivers approaching a railroad crossing aware of the need to stop ahead due to an oncoming or crossing train. In this way, the RCVW application will help reduce the number of drivers that are distracted or unaware of an approaching or crossing train, reducing the number of conflicts and crashes. Figure 1-3 summarizes the proposed RCVW application design.

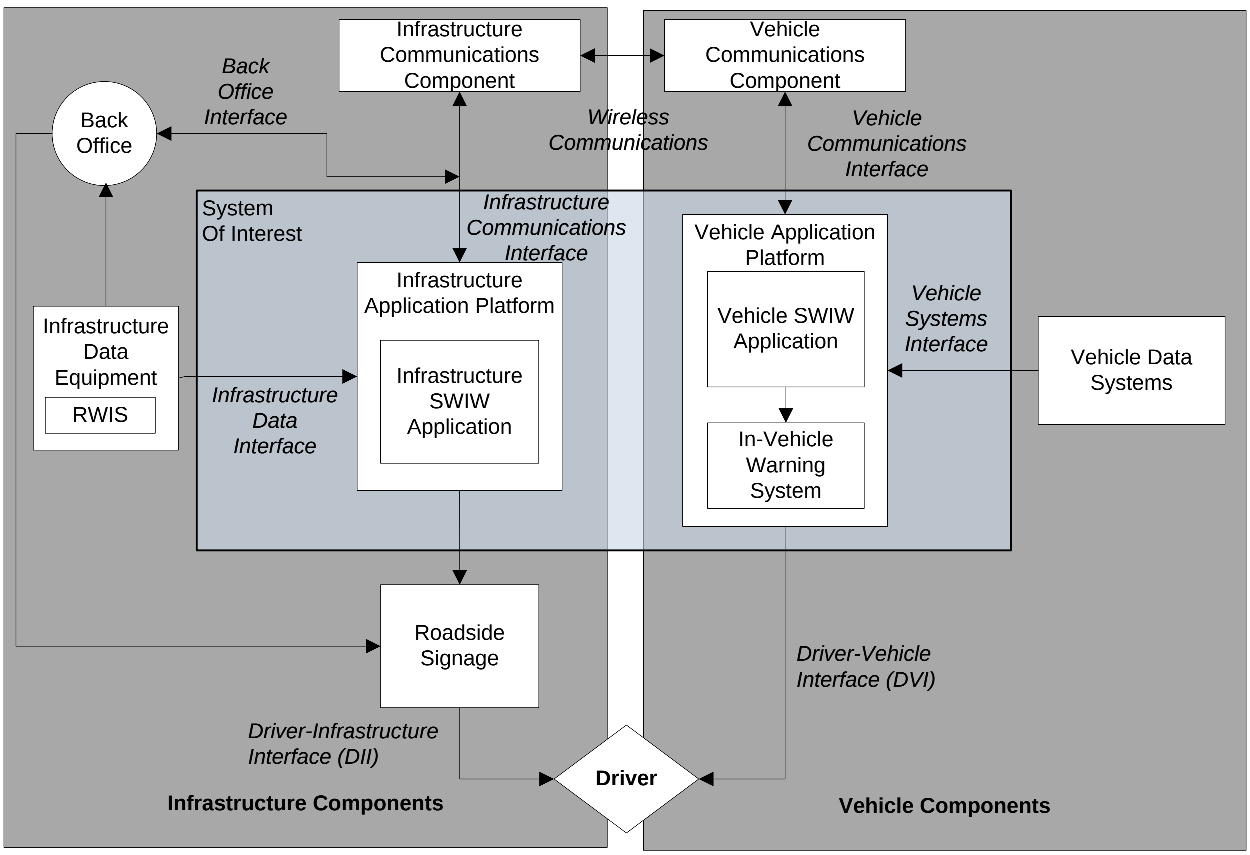


Source: Battelle

Figure 1-3. Railroad Crossing Violation Warning Application Diagram

1.3.3 System of Interest –Spot Weather Information Warning (SWIW) Application

The SWIW safety application is intended to improve safety in areas subject to localized adverse or inclement weather events, which may include relatively high-elevation or low-elevation areas that are more prone to reduced visibility, adverse surface conditions due to rain, snow, ice, and/or flooding, and high winds. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including onboard and roadside signage warning systems, to make drivers approaching an area with adverse weather conditions aware of the need to reduce speed or divert to safely navigate through or avoid the adverse weather impact area. In this way, the SWIW application will help to increase driver awareness of the severity of hazardous weather conditions, reducing the risk potential for conflicts and crashes. Figure 1-4 summarizes the proposed SWIW application design.

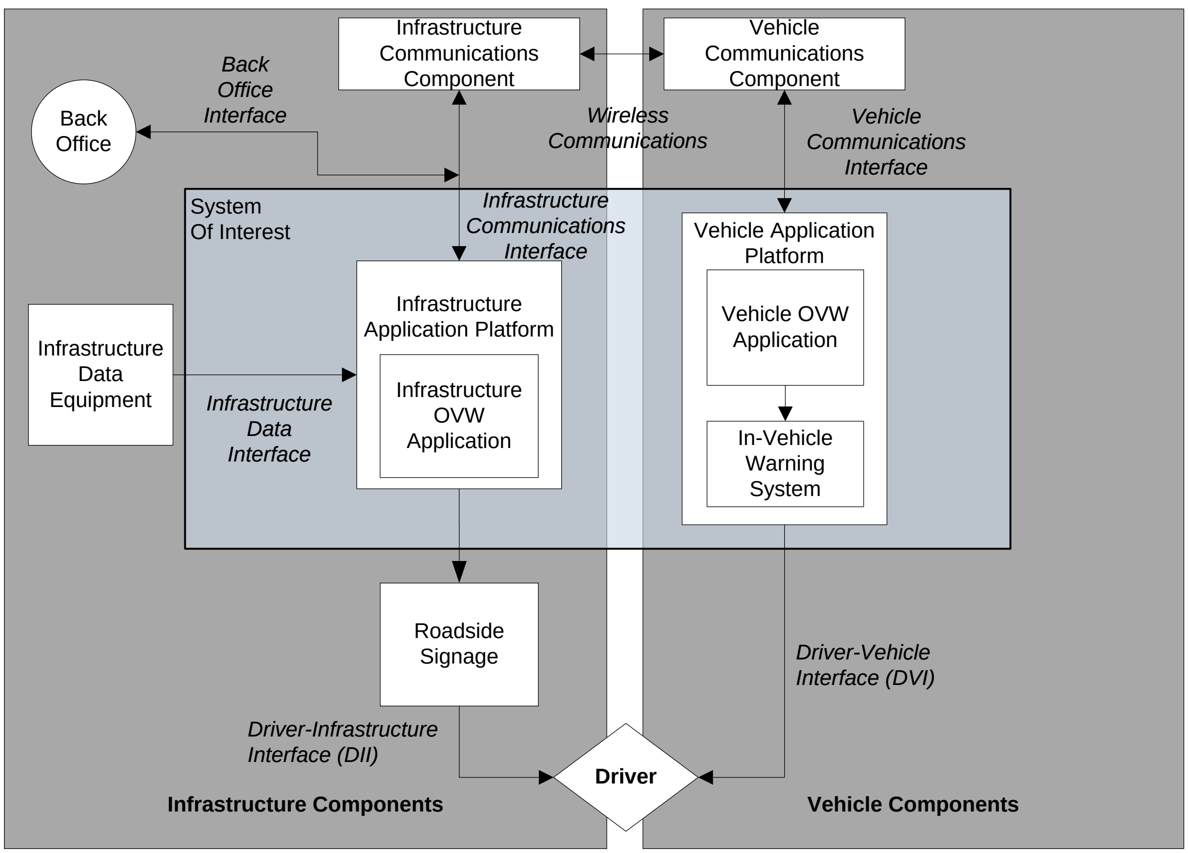


Source: Battelle

Figure 1-4. Spot Weather Information Warning Application Diagram

1.3.4 System of Interest – Oversize Vehicle Warning (OVW) Application

The OVW safety application is intended to help drivers of equipped and non-equipped oversize (i.e., overheight, overwidth, and overlength) vehicles avoid collisions with clearance restrictions (e.g., low height and/or narrow horizontal clearances, as may be found in bridges and tunnels). This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including onboard and roadside signage warning systems, to make drivers approaching a roadway clearance obstacle (e.g., low height or narrow horizontal clearance bridge or tunnel, toll plaza or other highway restriction) aware of the potential for a collision. In this way, the OVW application will help reduce the number of oversize vehicles that collide with roadway clearance obstacles, reducing the number of crashes and resulting property damage, injury, and loss of life. While this application will be commonly used by CMVs, it applies to all oversize vehicles (e.g., RVs). Figure 1-5 summarizes the proposed OVW application design.

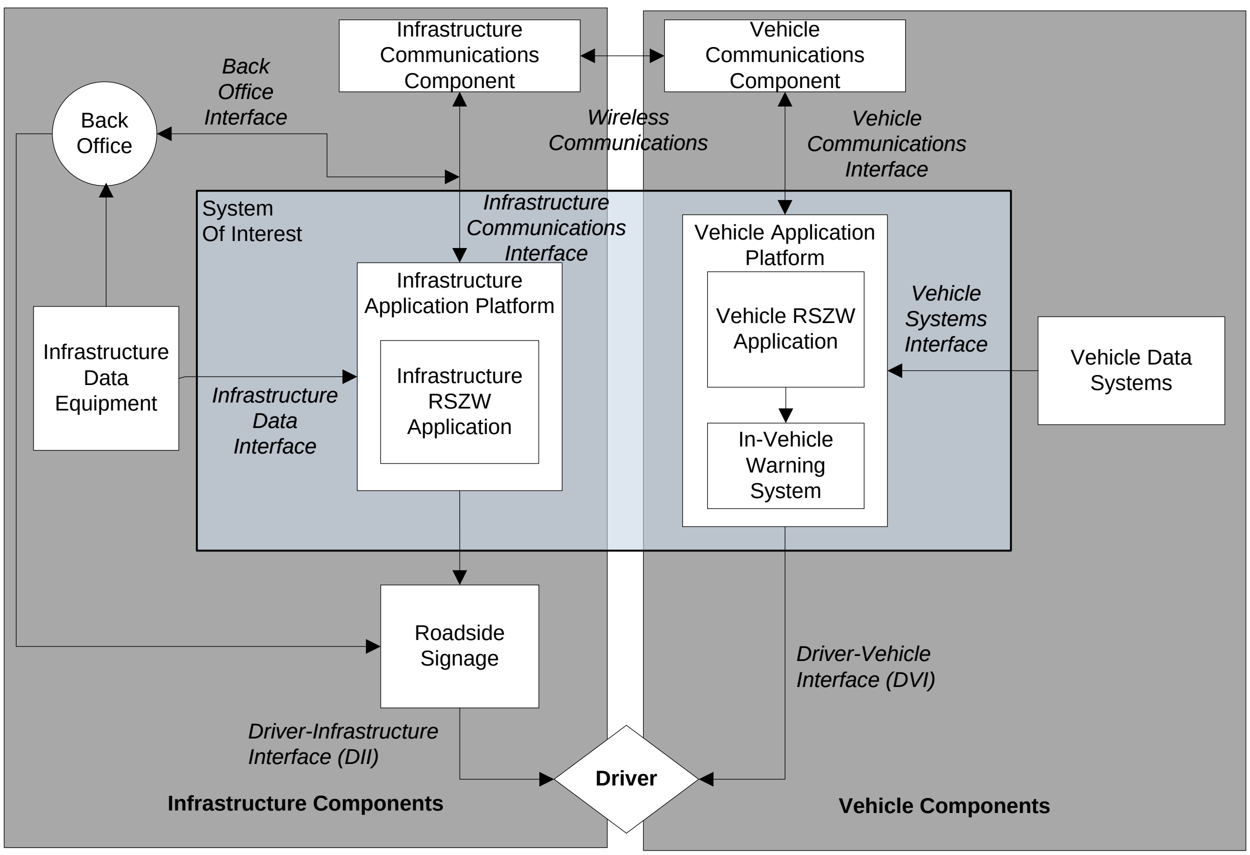


Source: Battelle

Figure 1-5. Oversize Vehicle Warning Application Diagram

1.3.5 System of Interest –Reduced Speed Zone Warning (RSZW) Application

The RSZW safety application is intended to alert or warn drivers of equipped and non-equipped vehicles who are approaching a reduced speed zone if they are operating at a speed higher than the zone's posted speed limit and/or if the configuration of the roadway is altered (e.g., lane closures, lane shifts). This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including onboard and roadside signage warning systems, to make drivers approaching a reduced speed zone aware of the potential for a crash due to changes in speed and roadway configuration. In this way, the RSZW application will help reduce the number of vehicles speeding in reduced speed zones and those vehicles unfamiliar with changed roadway configurations, reducing the number of crashes and resulting property damage, injury, and loss of life. Figure 1-6 summarizes the proposed RSZW application design.



Source: Battelle

Figure 1-6. Reduced Speed Zone Warning Application Diagram

2.0 Referenced Documents

The following documents form a part of this ConOps document to the extent specified herein. Unless otherwise specified, the relevant versions of these documents are those cited in the solicitation or contract.

<u>Crash Avoidance Metrics Partnership (CAMP) on behalf of the Vehicle Safety Communications 2 (VSC2) Consortium</u>

CICAS-V ConOps	Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Concept of Operations, v3.01 (2008).

<u>University Transportation Research Center/New York State Department of Transportation (UTRC/NYSDOT)</u>

UTRC/NYSDOT Report #8	Bridge-Vehicle Impact Assessment – Final Report (December 2011).

<u>U.S. Department of Transportation</u>

DOT HS 810 697	Crash Warning System Interfaces: Human Factors Insights and Lessons Learned, Final Report (2007).
DOT HS 811 492A	Vehicle Safety Communications – Applications Final Report (2011).
FHWA-HOP-08-024	Traffic Signal Timing Manual (2008).
FHWA-RD-03-065	In-Vehicle Display Icons and Other Information Elements, Volume I: Guidelines (2004).
FHWA–RD–98–057	Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO) (1998).
MUTCD-09	Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 edition, Federal Highway Administration, http://mutcd.fhwa.dot.gov/.
	National ITS Architecture, Version 7.0 (January 2012), Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, http://www.its.dot.gov/arch/index.htm.

	Connected Vehicle Core System Baseline Documentation:
	Concept of Operations (ConOps) (October 24, 2011);
	System Architecture Document (SAD) (October 14, 2011);
	System Requirements Specification (SyRS) (October 28, 2011);
	Deployment Critical Risk Assessment Report (October 28, 2011);
	Standards Recommendations (October 28, 2011).
	Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office, http://www.its.dot.gov/press/2011/connected_vehicle_coresystem_docs.htm
	National Bridge Inventory (November 2011). http://www.fhwa.dot.gov/bridge/nbi.htm.
	2007 FHWA ITS Deployment Tracking Survey on Crash Prevention and Safety. http://www.itsdeployment.its.dot.gov/itspreviousyears/ResultsStateNational.asp?ID=1568&rpt=M&filter=1&year=2007.
	2010 FHWA ITS Deployment Tracking Survey. Freeway information: http://www.itsdeployment.its.dot.gov/FM.aspx. Arterial information: http://www.itsdeployment.its.dot.gov/AM.aspx.
	Federal Railroad Administration (August 13, 2012) Crossing Collisions and Casualties by Year, at: http://oli.org/about-us/news/collisions-casulties.
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3.0 Current System or Situation

Presently, many infrastructure-based countermeasures or vehicle-autonomous systems have been implemented by public agencies and vehicle OEMs for the purpose of improving safety. These systems, until recently, have not typically integrated these two environments. Integrating data and systems for both roadside infrastructure and the vehicle can provide a richer information set for identifying driving hazards and providing more accurate and timely warnings to drivers of unsafe conditions at an intersection. However, as previously discussed, the purpose of this document is to develop the ConOps for five applications that either create new or expand existing safety improvement over the current practice by integrating these infrastructure and vehicle-based technologies. Consistent with the IEEE-1362 specification for ConOps documents, this section examines those current systems and technologies, both vehicle- and infrastructure-based, that are envisioned to provide some or all of the technology inputs into these future applications. Recapping Section 1.3, these targeted applications include:

- *Stop Sign Violation Warning (SSVW)* – Application designed to warn drivers that they may violate an upcoming stop sign based on their speeds and distance to the stop sign.
- *Railroad Crossing Violation Warning (RCVW)* – Application designed to warn drivers of the need to stop for crossing or approaching trains at an at-grade rail crossing.
- *Spot Weather Information Warning (SWIW)* – Application designed to use standalone weather systems to warn drivers about inclement weather conditions (i.e., fog, wind, adverse surface conditions, etc.) that may impact travel conditions.
- *Oversize Vehicle Warning (OVW)* – Application designed to provide warning to drivers of oversize vehicles (overheight/overlength/overwidth) for restricted clearances (e.g., height/width clearances of tunnels and/or bridges) ahead.
- *Reduced Speed Zone Warning (RSZW)* – Application designed to warn drivers of excessive speeds compared with the posted speed limit in reduced speed zones and changed roadway configurations. Reduced speed zones may include school zones, work zones, and populated areas.

The remaining discussion within this section describes each current system and its associated functionality.

3.1 Background, Objectives, and Scope

The success of existing roadside safety solutions varies, as do the methods for implementing the solutions. These countermeasures include relatively simple and effective techniques ranging from pavement treatments in the form of rumble strips to dynamic message signs (DMS) and to sophisticated radar-based intersection collision warning systems. Between are countermeasures that include Road Weather Information Systems (RWIS), speed warning systems, overheight or overwidth detection, and more. In addition to the nearly half a million signal systems helping to prevent crashes at intersections, there are advanced infrastructure-based systems deployed that support safety improvements along corridors and at unsignalized intersections.

In addition to infrastructure elements, vehicle manufacturers, particularly in the commercial and high-end passenger vehicle market, have invested in and promoted several forms of vehicle-based safety applications with the same end goal of reducing the number and severity of collisions and accidents. The following section documents a few of these safety-related solutions available on the market today that are expected to be leveraged for V2I safety applications.

Finally, research has already been conducted in connected vehicle technologies. In one example, the CICAS program integrated both vehicle-based and infrastructure-based technologies to help drivers approaching an intersection understand the state of activities within the intersection (http://www.its.dot.gov/cicas/). CICAS served to warn drivers about likely violations of traffic control devices (such as stop sign violations) and to assist drivers in safely completing maneuvers along the roadway or through cross traffic. Research results from these programs serves as fundamental building blocks for this ConOps.

System Goals

The goal of any of these existing systems and applications is consistent with the broader goal of USDOT, which is to save lives and reduce injuries by alerting drivers of potential conflicts so that drivers can take actions to prevent an incident from occurring, or at least reduce the magnitude and impacts of the incident.

The goal of the SSVW application is to provide in-vehicle warnings to drivers that, based on their speeds and distance to the stop sign, they may violate an upcoming stop sign. Presently, there are no widely acceptable deployments of systems operating at stop signs that detect the speed of an approaching vehicle. Although experimental deployments have taken place, these have known faults such that these systems are still under development.

The goal of the RCWV application is to provide approaching traffic information to support driver decisions in safely approaching and traversing at-grade rail crossings, beyond the standard safety countermeasures (flashing lights, warning bells, cross gates, etc.) that are typically installed.

The goal of the SWIW application is to provide automated warnings to drivers of unsafe conditions in areas that frequently experience fast-developing inclement weather conditions (i.e., fog, wind, ice, dust, etc.), through the use of existing environmental sensors and static signs with flashers/DMS.

The goal of the OVW application is to provide oversize vehicle drivers (e.g., CMV drivers, RV drivers) with advance notification that their vehicle cannot safely pass through roadway clearance obstacles (e.g., low or narrow tunnel and bridge clearances) while providing them with ample opportunity to detour around the low clearance area.

The goal of the RSZW application is to warn drivers that their current speed is too high to safely traverse upcoming reduced speed zones (e.g., school zones, work zones, and/or populated areas). This application can be based upon basic radar detection sensors that measure speed and then provide speed warnings via flashing beacons, DMS, or other equipment.

3.2 Operational Policies and Constraints

Policy Influence on Safety Systems

As discussed above, the primary goal of these systems is to provide drivers with advance warnings of unsafe conditions at upcoming intersections or corridors. Local, regional, state, and national policies all influence how these systems are designed, installed, operated, and maintained. Examples of the policy questions that may influence these systems in a given area include the following:

- Should all types of users (i.e., vehicles, trucks, pedestrians, etc.) be treated equally or should one particular user class be prioritized over the others for certain applications?
- Within a region, should all of these warning systems have a consistent design and operation? Should the same warnings be provided throughout a region/state, or can different types of systems provide different warnings?
- What Federal and State-level standards need to be followed in the use of static and dynamic signing in these warning systems?
- What guidelines are there for experimental signs and warning systems not addressed by current design standards?

Hardware and Software Considerations

The hardware and software deployed at an intersection or along a corridor depends upon the geometry of the intersection or corridor, the safety goal at that feature, its location, and the availability of power and communications. The geometry of the intersection or corridor and the safety goal (alerting drivers, supporting decisions) determine the information to be conveyed to the driver and the location at which the information is conveyed. The location of the intersection or corridor typically governs whether power and communications are available or, if required need to be installed at that location. Within these constraints and considerations the designer selects the type of sensor hardware to be installed, the type of message hardware to be installed, the location at the intersection or corridor, and software that controls the messaging and information.

Examples of hardware and software constraints that might impact system operations at an intersection or roadway include:

- Types of messages that may be displayed to drivers approaching the intersection, speed zone, or hazardous location;
- Types of environmental data collected in an RWIS that may be used to automate warning drivers of inclement weather conditions ahead;
- Power consumption of various hardware components (i.e., use of solar power or a dedicated power source);
- How different types of system users (vehicles) will be detected and accommodated;
- Ability of equipment to accommodate regional or corridor communication strategies (i.e., fiber, modem, radio, etc.); and
- The hardware and software used by neighboring agencies and the partnership possibilities between them (i.e., cost-sharing).

Operational Constraints

System operations vary significantly depending on the type of warning system. The ability to utilize nearby power sources impacts the decision on whether or not solar power panels are required to provide power to hardware and software components. The presence of nearby static warning signs may impact the placement of any additional signage required for system operations.

Some current system algorithms in warning systems only use sensors (loops, radar, etc.) to detect whether vehicles are present or not. Other system algorithms take input from supplemental detection equipment, such as Environmental Sensor Stations (ESS) and speed detection equipment, to determine weather conditions, such as fog, rain, or icy conditions; and traffic behavior, such as the presence of slow or stopped traffic ahead. Even more complex system algorithms take the detected data and then automate messages to appear on DMS as a warning to drivers of the weather and/or traffic conditions ahead, thus allowing public works staff to be available for performing other critical tasks.

Personnel Constraints

Public works agency resources face ever-increasing demands to accomplish more with fewer staff. The systems under consideration must be simple and straightforward to maintain and operate with limited requirements for inspection. Consideration is needed for maintenance training requirements in light of potential staff retention limitations and turnover.

3.3 Description of the Current System or Situation

As previously outlined, existing safety systems include both infrastructure-based and vehicle-based systems. Details of how these existing systems operate, along with a brief description of their respective deployment environments, are provided below.

3.3.1 Current Infrastructure-Based Approach for Intersection and Corridor Safety

3.3.1.1 Stop Sign Violation

Presently, there are no known widely accepted deployments of systems operating at stop signs that detect the speed of an approaching vehicle. Although experimental deployments have taken place, these have known faults such that these systems are still under development. Instead, it is more common for stop signs to be equipped with small flashing beacons on top or surrounding the border of the sign that flash on either a continuous basis or based on motion detected at a pre-set distance from the sign.

3.3.1.2 Railroad Crossing Warning

Active Rail Crossing Warning systems have been widely deployed and have proven an effective method of improving safety and operations at highway-railroad grade crossings. Standard active warning devices commonly found at highway-railroad grade crossings include: flashing light signal, cantilever flashinglight signal, automatic gate, warning bells, and additional flashinglight signals.

Regardless of the type of active warning control system deployed, a train detection system must exist to activate the devices. Five basic types of train detection systems are in use today[2]:

- Direct current (DC) track circuit.
- AC-DC track circuit.
- Audio frequency overlay (AFO) track circuit.
- Motion-sensitive track circuit.
- Constant warning time track circuit.

Crossing traffic control devices that are train activated typically incorporate some “fail-safe” design principles. The fail-safe system is designed to give a warning indication of an approaching train whenever the system has failed.

Additional technology has been deployed in various locations as a means of providing enhanced warnings to drivers and pedestrians regarding approaching trains, beyond the standard safety countermeasures. While the following examples do not serve as direct predecessors to the envisioned V2I safety application, they do show how additional safety benefits have been realized for at-grade crossing through the use of additional signage that leverage standard contact closures. These examples depict existing RCW systems that have been tested and are currently operational.

Maryland MTA Second Train Coming Warning System

The Maryland Mass Transit Administration (MTA) installed DMS in 1997 at an at-grade highway-rail intersection (HRI) that featured light-rail trains crossing on separate tracks at speeds of 50 mph from both directions. The MTA noted that the operation of crossing gates at the intersection could be confusing to highway drivers, who begin to travel through the intersection when the crossing gates ascend after the first train passes, only to be stopped again as the gates then descend again for the second train approaching from the other direction.

Whenever two trains are detected by an external contact closure on the rail tracks, the DMS is activated and presents a series of messages to drivers that are stopped behind crossing gates at the HRI. The first message displayed features “WARNING” in a flashing mode, followed by “2nd Train Coming” in a steady mode, followed by an animation of the two trains crossing the intersection from both directions, one after the other. The series of messages continues to display until after the trains have cleared the intersection. A before-and-after evaluation report completed in 1998 concluded that the risky driver and pedestrian behavior at the intersection was reduced by more than 80 percent.[3]

[2] Railroad-Highway Grade Crossing Handbook – Revised Second Edition. U.S. Department of Transportation, Federal Highway Administration, Washington, DC, August 2007.

[3] Parker, S.A. Second Train Coming Warning Sign Demonstration Projects. TCRP Research Results Digest. November 2002, Number 51.

LACMTA Second Train Coming Warning System

The Los Angeles County Metropolitan Transportation Authority (LACMTA) installed DMS in 2001 at a light-rail station that included a pedestrian crossing of an at-grade roadway-rail intersection that had a history train/pedestrian accidents resulting in fatalities. When two trains are detected as approaching the station from both directions, the DMS presents a graphical illustration of both approaching trains to pedestrians waiting to cross. An external contact closure on the rail tracks is made when two trains are approaching the crossing at the same time, which then activates the DMS. Once energized, the sign then alternately displays the left train/left arrow and the right train/right arrow in flashing mode until the trains have cleared the HRI. Figure 3-1 shows the DMS installed for the LACMTA Second Train Coming Warning System.

Source: Transit Cooperative Research Program Research Results Digest No. 51, November 2002

DMS Warning for Northbound LRT Train	DMS Warning for Southbound LRT Train

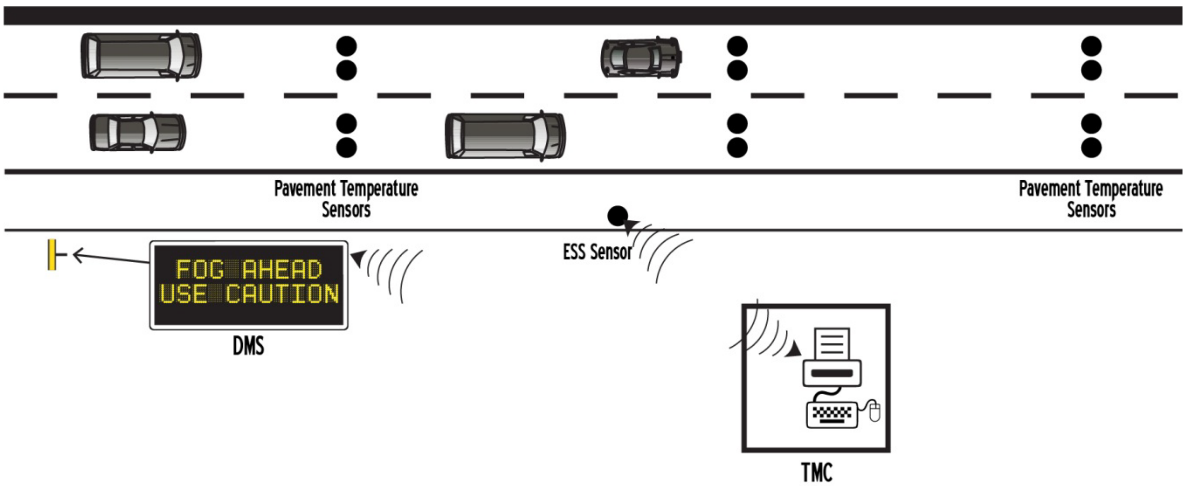
Figure 3-1. LACMTA Second Train Coming Warning System

3.3.1.3 Spot Weather/Road Weather Information Systems

Spot Weather Systems and RWIS have been deployed throughout the country as a means of providing automated warnings to drivers about fast-developing inclement weather conditions that impact travel conditions. The following installations depict examples of systems that have been tested and are currently operational.

VTrans RWIS Automation System

The Vermont Agency of Transportation (VTrans) oversaw the installation of a spot weather system in 2011 along a 65-mile corridor of I-89 (Figure 3-2). The system integrated air and pavement temperatures detected from five pre-existing RWIS equipment sites with additional in-pavement temperature sensors that were installed to provide additional coverage for the corridor. Data from these sensors is sent every 5 minutes to a central server where custom algorithms are performed on the data to determine if weather warning messages should be displayed on DMS. The server can command site-specific DMS to display messages about inclement weather conditions (fog, ice, snow, etc.). VTrans personnel receive updates about messages that are displayed and can proactively respond to changes in weather as needed.

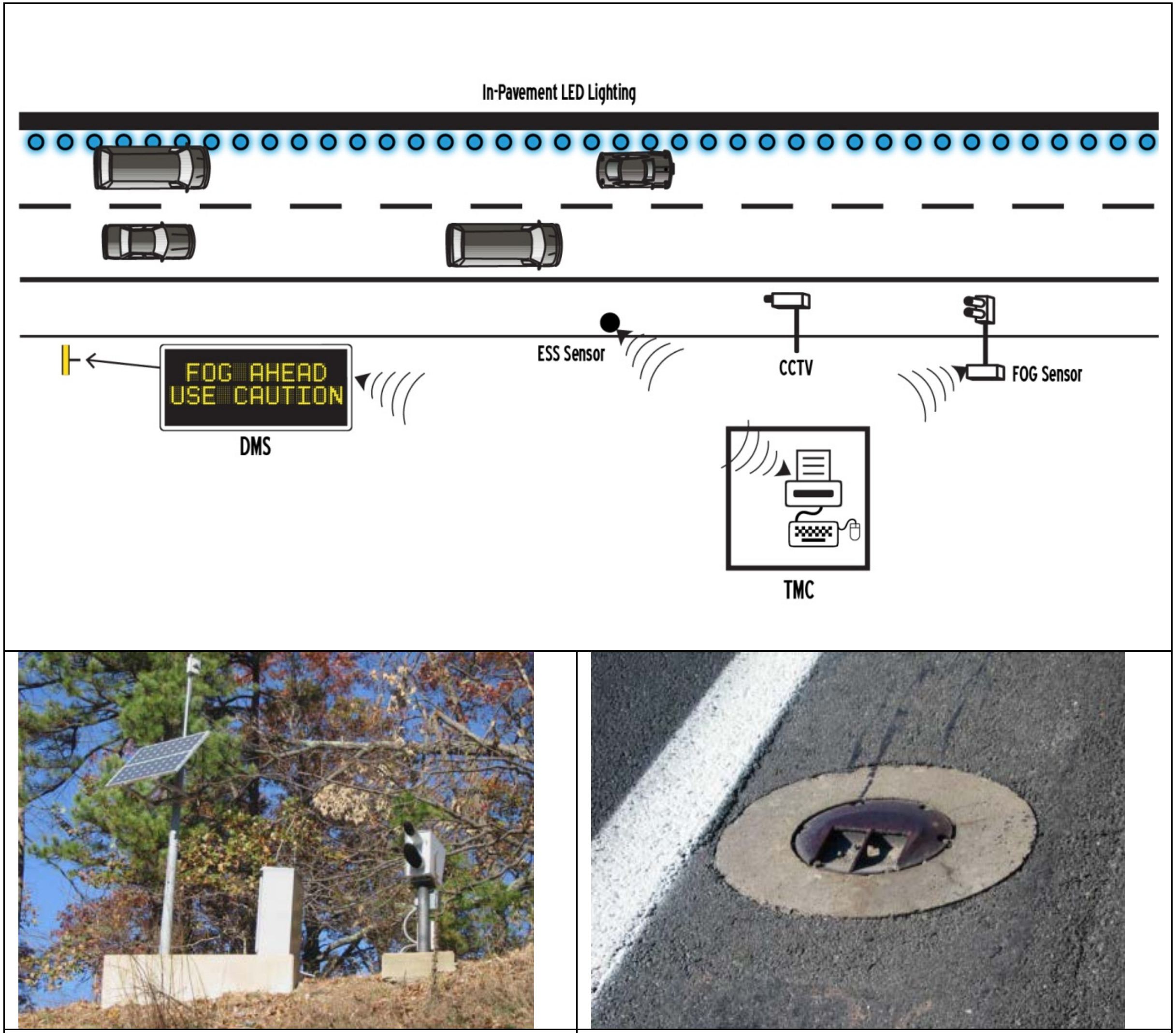


Source: URS Group, Inc.

Figure 3-2. VTrans RWIS Automation System Deployment

Virginia DOT Fog Warning System

The Virginia DOT (VDOT) installed a Fog Warning System along a 6-mile stretch of I-64 as it traverses the Afton Mountain region of central Virginia. Multiple environmental sensor stations (ESS) were installed along the corridor to detect the presence and intensity of fog conditions and provide updates and alerts to Traffic Management Center (TMC) staff. In-pavement Light-Emitting Diode (LED) lighting can be activated by TMC staff to provide drivers with a visual indication of the shoulder location, and DMS can be activated at both ends of the mountain to warn drivers approaching the area of fog conditions. In extreme fog conditions, in-pavement lighting and DMS messages are activated automatically to provide immediate warnings to drivers of heavy fog on the roadway. Figure 3-3 depicts an installation of the VDOT Fog Warning System and in-pavement lighting.



VDOT ESS Equipment | Typical In-Pavement LED Lighting

Source: Upper - URS Group, Inc.

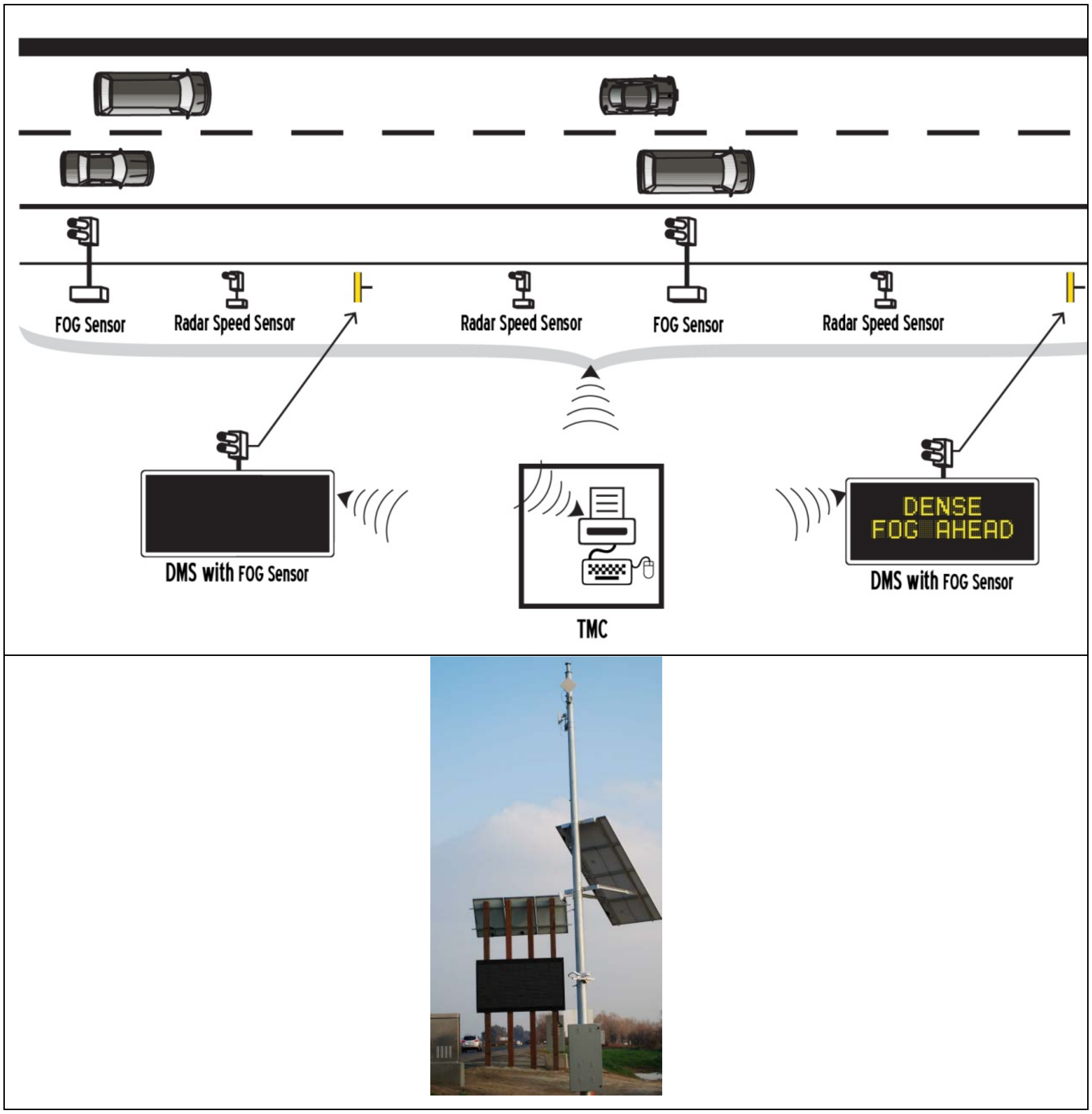
Figure 3-3. Virginia DOT Fog Warning System

Caltrans Fog Detection and Warning System

The California Department of Transportation (Caltrans) installed a Fog Detection and Warning System in 2009 along a 13-mile stretch of State Route 99 south of Fresno. ESS that detect visibility (fog) conditions have been installed at half-mile intervals along the corridor, along with radar sensors at quarter-mile intervals to measure travel speeds, as well as traffic volume, classification, lane occupancy, and presence in both directions of travel for the purpose of understanding speed differential at downstream locations on the freeway.

Data are transmitted wirelessly back to a Caltrans TMC facility, where software automates the process of generating an appropriate message to be displayed on DMS that are also installed at half-mile intervals on the corridor. TMC staff can also override the messages displayed on the DMS to provide more detailed information if needed. In the event of loss of communications to the TMC, field software will analyze visibility and radar sensor data to determine the appropriate DMS message to display. Figure 3-4 shows an installation of the ESS and DMS used in the Caltrans system.[4] Further information on the messages displayed based on the conditions detected is contained in Section 3.4.

[4] Berman, Michael, Liu, John, and Justison, Liz. Caltrans Fog Detection and Warning System White Paper. Available at: http://gs.flir.com/uploads/file/white-papers/caltrans%20fog%20detection%20and%20warning%20system.pdf. Accessed on July 13th, 2012.

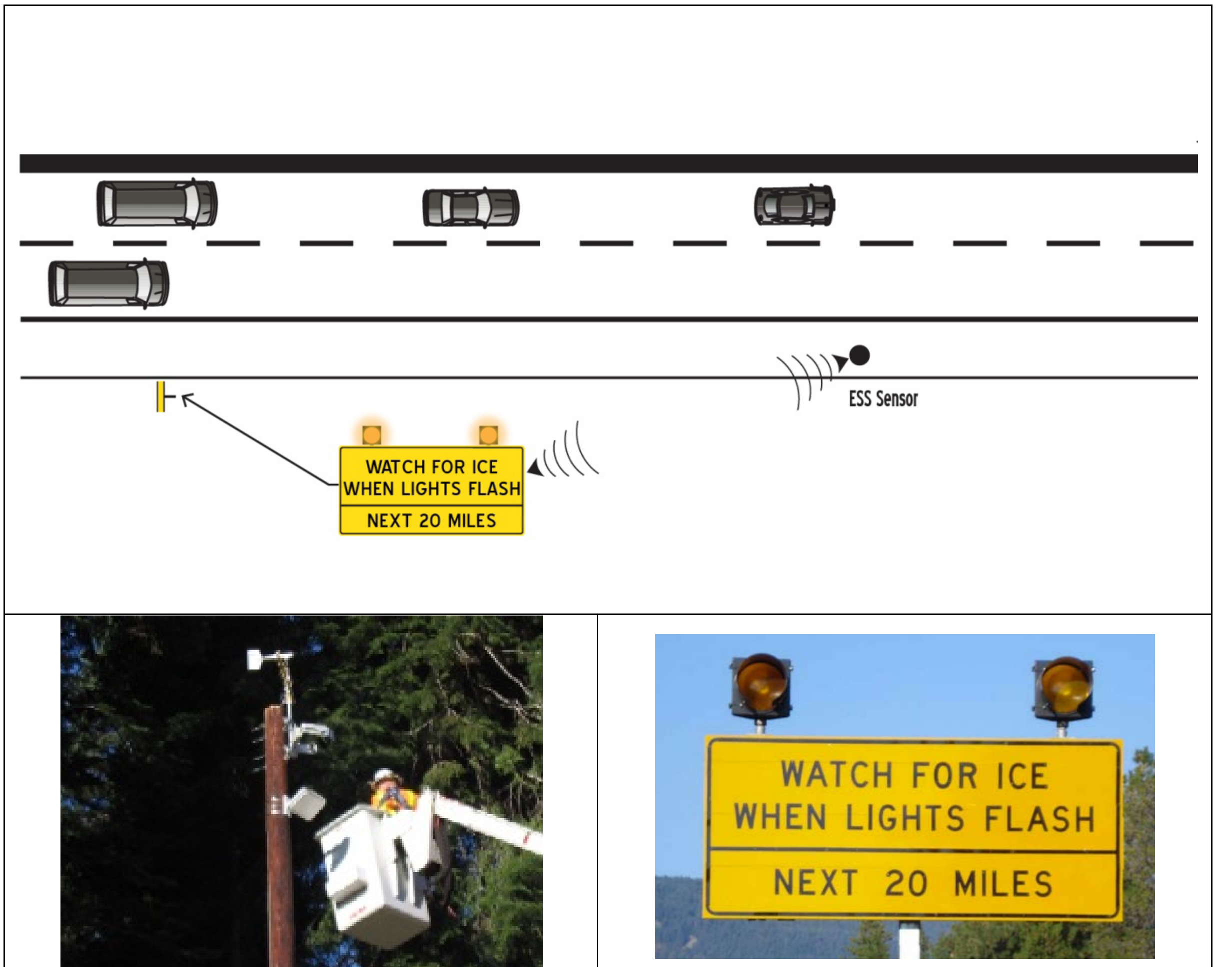


Source: Upper Illustration – URS Group, Inc.; Lower Photos – Federal Highway Administration Best Practices for Road Weather Management, June 2012

Figure 3-4. Caltrans Visibility/Speed Sensors and DMS

Oregon DOT Butte Creek Ice Warning System

Oregon Department of Transportation (ODOT) installed an Ice Warning System in November 2005 to actively warn motorists of potentially icy driving conditions along a 20-mile stretch of State Route 140 near Butte Creek. The system consists of an ESS linked to two static signs with flashing beacons on both ends of the corridor warning travelers of icy conditions. When the threshold conditions (a combination of pavement temperature, humidity, and moisture as measured by the ESS) are met, the flashing beacons will automatically turn on. Figure 3-5 depicts the equipment and the signage of the ODOT Butte Creek Ice Warning System.[5] An evaluation of the system in 2009 found that travel speeds measured at the ESS site decreased by 9.5 mph when the beacons were activated, indicating that the system was meeting its intended purpose.[6]



ESS Location near Butte Creek	Static Warning Sign with Flashing Beacons

Source: Upper Illustration – URS Group, Inc.; Lower Left Photo – Oregon DOT Butte Creek Ice Warning System Web Page; Lower Right Photo – 2009 National Rural ITS Conference Presentation Butte Creek Ice Detection and Advanced Warning System Evaluation

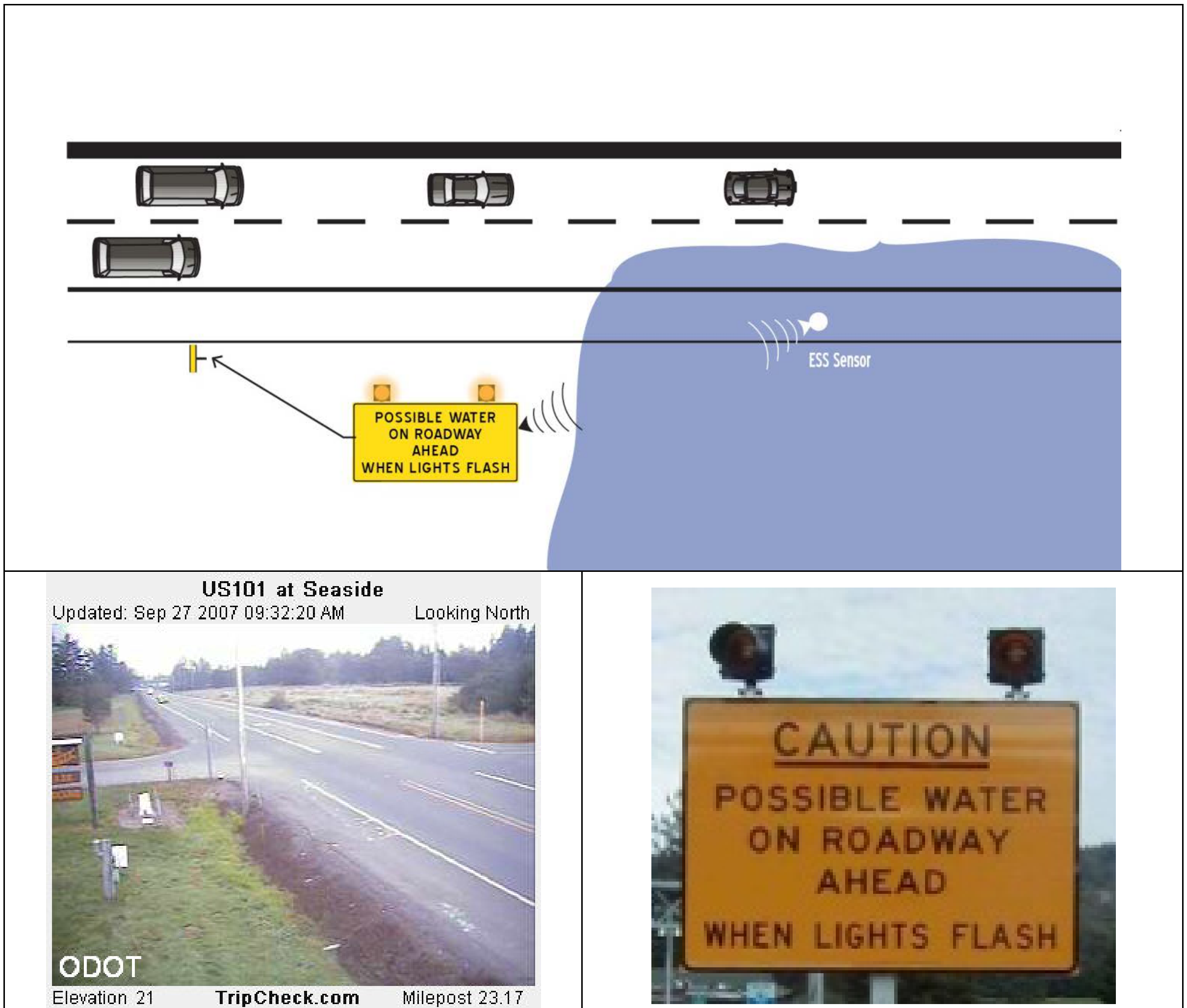
Figure 3-5. Oregon DOT Butte Creek Ice Warning System

[5] Oregon Department of Transportation. Butte Creek Ice Warning System. http://www.oregon.gov/ODOT/HWY/ITS/pages/project_buttecreek.aspx. Accessed on July 13th, 2012.

[6] Lindgren, R., and S. St. Clair. Butte Creek Ice Detection and Advanced Warning System Evaluation. August 26, 2009 National Rural ITS Conference. Available at: http://www.nritsconference.org/downloads/Presentations09/G1_Lindgren.pdf. Accessed on July 13th, 2012.

Oregon DOT Flood Warning System

ODOT also installed a Flood Warning System on Highway 101 near Seaside to warn drivers of water on the roadway and reduce the need for ODOT maintenance personnel to monitor water levels at this location. An ESS that detects water levels was installed at the low point in the road and connected to a series of advance warning signs at each end of the flood-prone area of roadway. Flashing beacons installed on static signs are activated when flood conditions are imminent to warn drivers. The system also transmits water level data to district offices so that maintenance personnel can be prepared to respond when conditions warrant. This data are also made available to the public via the Internet. Figure 3-6 presents the location and signage of the ODOT Flood Warning System.[7]



CCTV Image of US Highway 101 Flood-Prone Location	Static Warning Sign with Flashing Beacons

Source: Upper Illustration – URS Group, Inc.; Lower Photos – Oregon DOT

Figure 3-6. Oregon DOT Flood Warning System

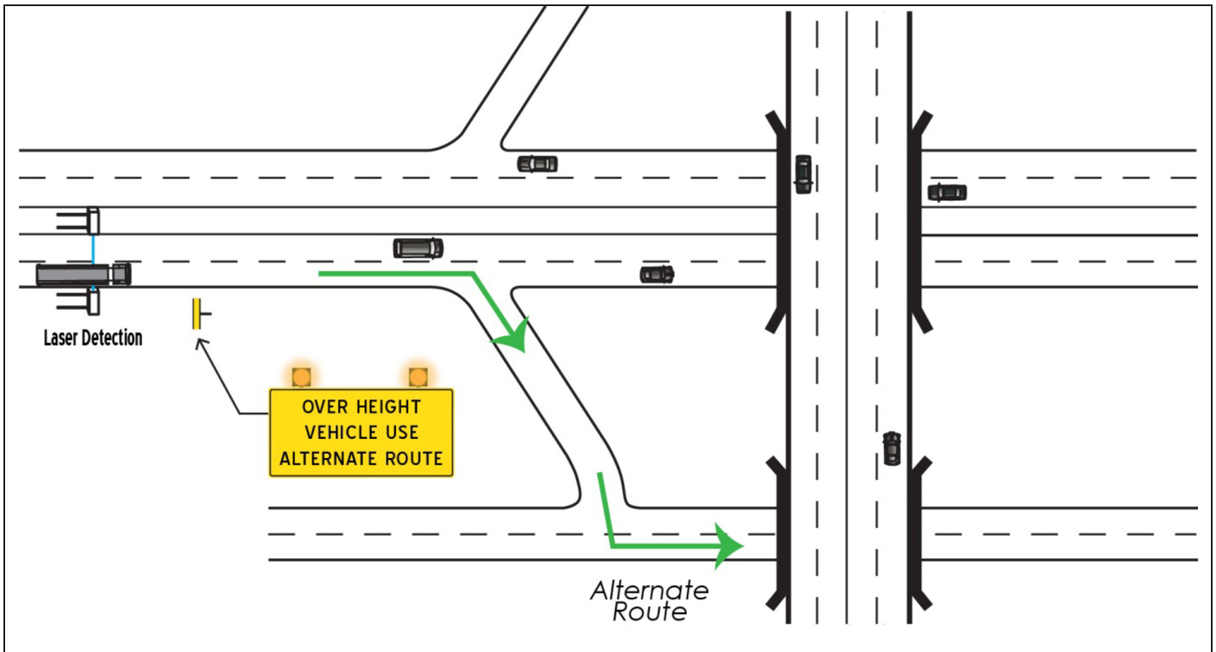
[7] Oregon Department of Transportation. Seaside Flood Warning System. http://www.oregon.gov/ODOT/HWY/ITS/pages/project_fwds.aspx. Accessed on July 13th, 2012.

3.3.1.4 Oversize Detection Systems

Oversize Detection systems have been deployed by many state DOTs as a means of reducing the potential for oversize vehicle collisions with roadway clearance obstacles such as bridges, tunnels, toll plazas, and other roadway infrastructure with low vertical and/or narrow horizontal clearances. The following installation depicts an example of an oversize detection system that has been tested and is currently operational.

Tennessee DOT System

The Tennessee DOT (TDOT) oversaw the installation of an Overheight Vehicle Detection System in 2006 in Memphis along areas of I-55, I-40, and I-240 that lead to a Mississippi River bridge crossing with low clearance. Roadside equipment with laser detection was installed at the proper height to determine the presence of overheight vehicles. Once detected, an overhead DMS downstream of the detection was configured to display an overheight warning message and instruct the vehicle to take an upcoming exit as an alternate route around the low-clearance bridge. Central software at a TDOT office also receives a notification whenever overheight vehicles are detected and sends a text message to DOT staff. Since beginning operation in 2006, TDOT staff estimate that the system has reduced incidents by about 75%. Figure 3-7 presents an illustration of the installation of the TDOT Overheight Vehicle Detection System.



Overheight Vehicle Detection System Deployment Overview

Source: URS Group, Inc.

Figure 3-7. Tennessee Overheight Vehicle Detection System

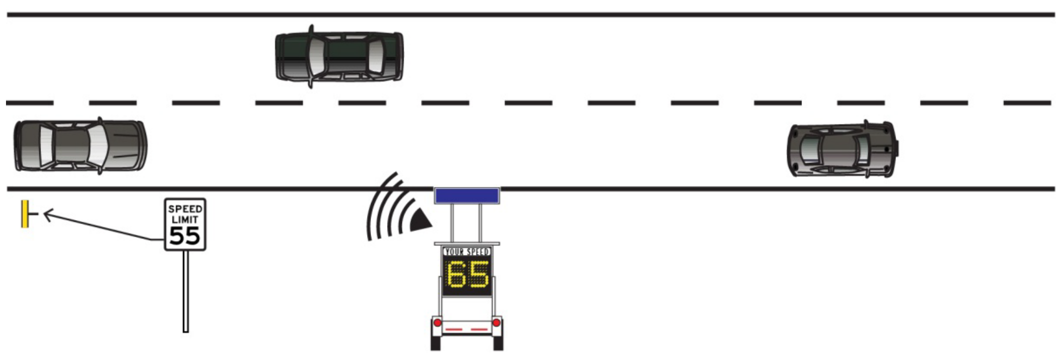
3.3.1.5 Speed Warning (SW)

Multiple speed warning systems have been deployed throughout the country in approaching speed zones and populated areas as a means of reducing vehicle crashes and motorist fatalities. The following four installations depict examples of speed warning systems that have been tested and are currently operational.

Portable Trailer Installation

Multiple installations of SW systems have been deployed throughout the country on portable trailers in work zones, school zones, and other areas to provide dynamic warnings to vehicles of their current speeds in relation to the posted speed. Various types of trailers and an illustration of their deployment are depicted in Figure 3-8. The location of these signs will vary depending on the system's objective, such as improving worker safety in work zones or being used as a traffic-calming device in local neighborhoods. Radar detection is commonly used as the speed detection method for vehicles approaching the portable trailer. A 2005 study of the types of applications depicted in Figure 3-8 revealed that devices displaying an approaching driver's speed are effective at reducing speeds and improving work zone speed limit compliance, although many drivers tend to travel as fast as they feel comfortable, absent the threat of law enforcement in the area.[8]

[8] Brewer, Marcus A. ; Pesti, Geza ; Schneider IV, William H. "Identification and Testing of Measures to Improve Work Zone Speed Limit Compliance" Federal Highway Administration, FHWA/TX-06/0-4707-1, 2005. Available at: http://tti.tamu.edu/documents/0-4707-1.pdf. Accessed on July 16th, 2012.



Portable Trailer Speed Warning System Deployment Overview

Solar-Powered SW Portable Trailer

Work Zone SW Application with Portable DMS

Source: Upper Illustration – URS Group, Inc.; Lower Photos – Texas Transportation Institute, Identification and Testing of Measures to Improve Work Zone Speed Limit Compliance, October 2005

Figure 3-8. Types of Portable Trailer SW Installations

Fixed SW Installations

Multiple installations of SW systems have been deployed at fixed locations to reduce speeds for traffic approaching reduced speed zones or in neighborhood areas. Figure 3-9 depicts one installation of a SW system in the community of Kirkland within King County, Washington, on 108th Avenue NE near 134th St. and an illustration of its deployment. This system was installed in 2002 and uses radar detection to provide dynamic warnings of actual speeds compared to the posted speed limit of 25 mph. Four signs have been installed in a neighborhood near an elementary school. The results of a 2002 before-and-after study revealed that traffic speeds decreased at three of the four locations, ranging from 4.26% to 7.15%, or from 1.19 mph to 2.21 mph.[9]

Further research on the effectiveness of SW systems was conducted in 2005 by Texas Transportation Institute (TTI) at a number of locations in Texas. Seven sites were evaluated before and after systems were installed, including a school speed zone, two transition speed zones in advance of a school speed zone, two sharp horizontal curves, and two approaches to signalized intersections on high-speed roadways. All SW systems utilized the same type of radar equipment for the purpose of speed detection.

Results indicated that average speeds were reduced by 9 mph at the school speed zone, but speed reductions were less dramatic at all other locations, with an average of 5 mph or less, depending on the location tested. As expected, motorists traveling faster than the posted speed reduced their speed more significantly in response to the SW systems than did motorists traveling at or below the posted speed limit. In general, it was concluded that SW systems are effective at reducing speeds in permanent applications, if appropriate site conditions apply.[10]

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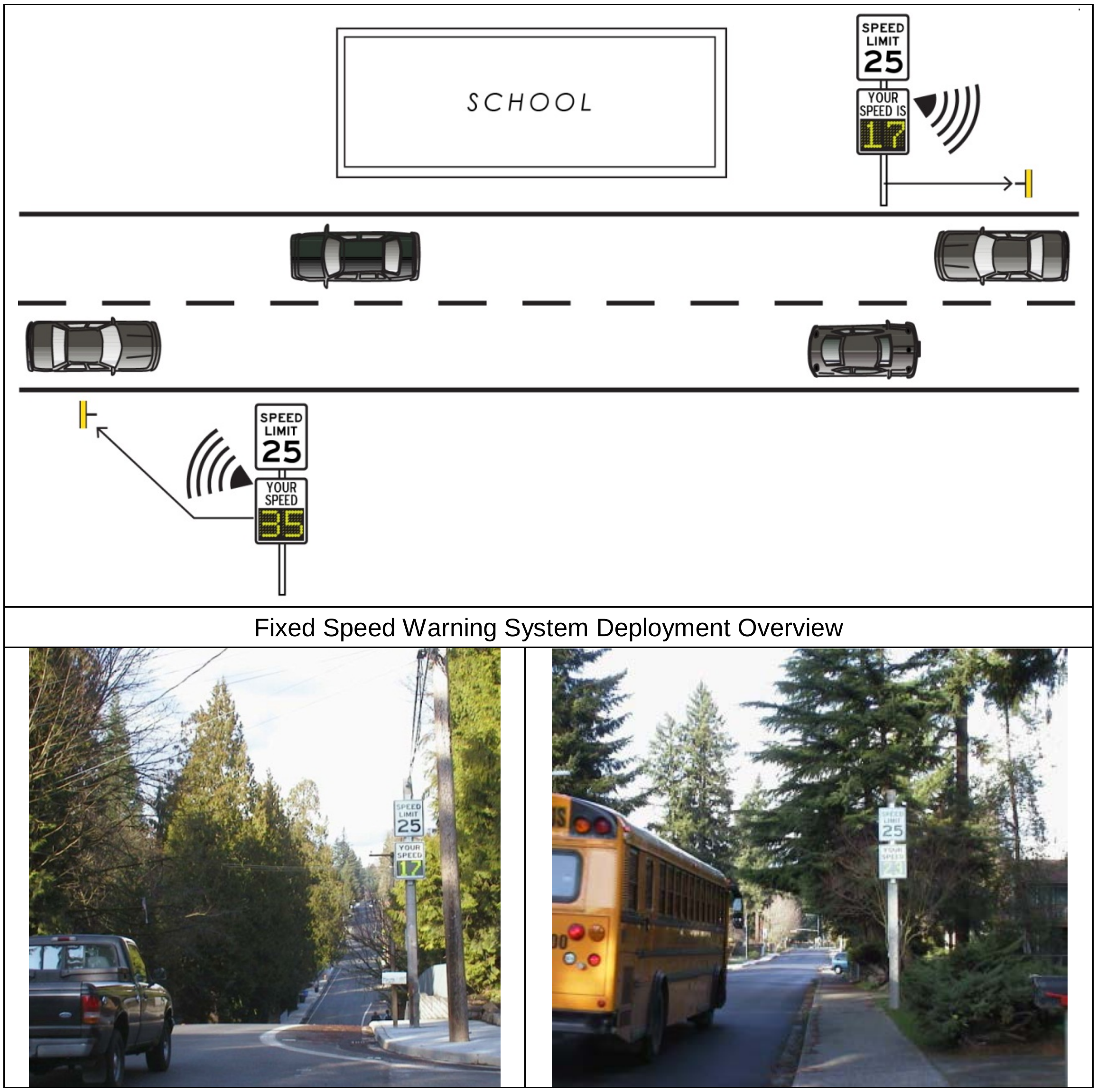
[9] Chang, Kevin, Nolan, Matthew, and Nihan, Nancy L. (2004) Radar Speed Signs on Neighborhood Streets: An Effective Traffic Calming Device? Available at: http://www.ite.org/traffic/documents/AB04H1501.pdf. Accessed on July 13th, 2012.

[10] Elisabeth R. Rose and Gerald L. Ullman (2003). Evaluation of Dynamic Speed Display Signs (DSDS). Federal Highway Administration, FHWA/TX-04/0-4475-1. Available at: http://tti.tamu.edu/documents/0-4475-1.pdf. Accessed on July 13th, 2012.



Source: Upper Illustration – URS Group, Inc.; Lower Photos – Institute of Transportation Engineers Annual Meeting Compendium, 2004

Figure 3-9. King County, Washington SW Installations

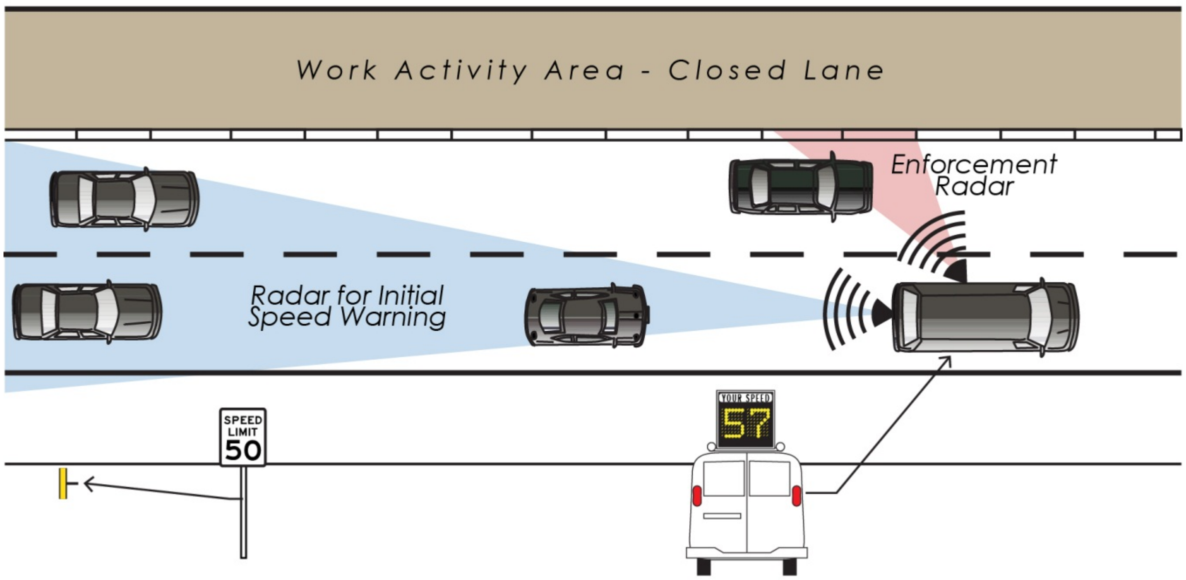
Mobile SW Systems

Mobile SW systems have been deployed in work zones to alter driver behavior by reducing vehicle speeds in work zones and enhance speed enforcement efforts by State Police. The Illinois Department of Transportation (IDOT) currently uses a mobile SW system (referred to as Speed-Photo-Enforcement [SPE]) that employs trained Illinois State Police officers that drive vans in highway work zones throughout all five regions of the state. The vans are equipped with two speed-detection radar units that measure vehicle speeds at a long distance (about one-quarter to one-half mile behind the van) and a short distance (about 150 feet from the van).

Vehicle speeds are displayed on a DMS display attached to the top of the van. Speeding drivers can reduce their speed once they are first detected at the longer distance and their actual speed is first displayed. If the driver's speed measured at the short distance is greater than a specified value, two onboard cameras are activated to take pictures of the driver and the rear license plate of the vehicle. Figure 3-10 contains an image of the van and a graphic of the photo enforcement strategy. An analysis of the initial deployment of the system in 2006 revealed a significant reduction in the speeds of cars and trucks by 3 to 8 mph in work zones.[11] The system, along with educational campaigns and work zone traffic control improvements, has also helped to reduce work zone fatalities from a high of 44 in 2003 to 31 in 2009.[12] Based on the success of this system, other states (Maryland, Oregon, Washington) have also created similar mobile speed enforcement initiatives.

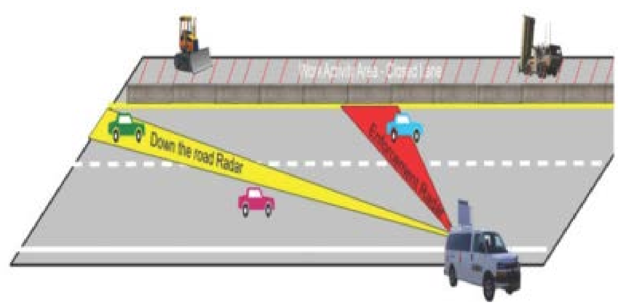
[11] Benekohal, R.F., Chitturi, M.V., Hajbabaie, A., Wang, M.H., and Medina, J.C.. "Automated Speed Photo Enforcement Effects on Speeds in Work Zones." Transportation Research Record: Journal of the Transportation Research Board, Issue 2055, 2008, pp 11-20.

[12] Tobias, P. "Research Pays Off: Automated Speed Enforcement Slows Down Drivers in Work Zones." TR News, Number 277 November–December 2011, pp. 29-31.



Mobile Speed Warning System Deployment Overview

Illinois Mobile Speed Warning Van



Speed Radar Detection at Two Locations

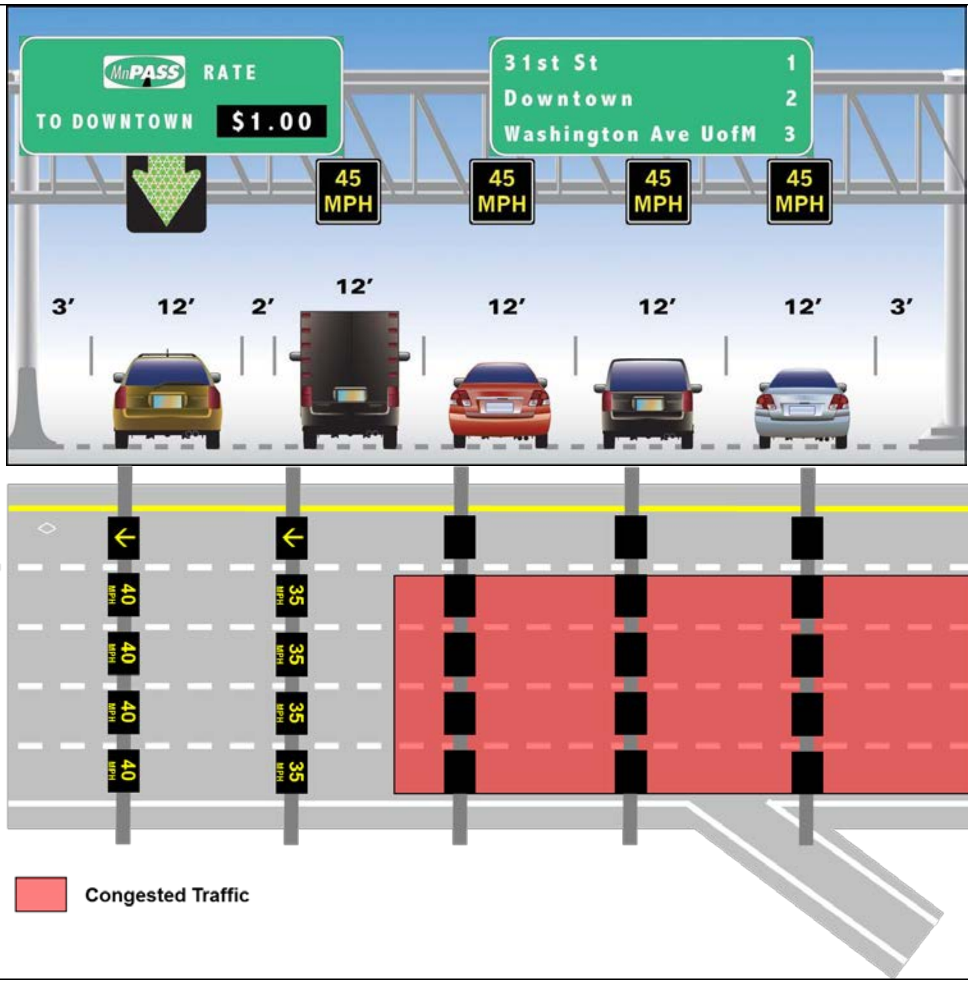
Source: Upper Illustration – URS Group, Inc.; Lower Photos – TR News, Number 277 November–December 2011

Figure 3-10. IDOT Mobile Speed Warning System[13]

[13] Priscilla Tobias. "Research Pays Off: Automated Speed Enforcement Slows Down Drivers in Work Zones." TR News, Number 277 November–December 2011, pp. 29-31.

Active Traffic Management

SW applications have also been incorporated within larger Active Traffic Management (ATM) installations for the purposes of reducing travel speeds based on the detection of slowed traffic upstream. Figure 3-11 depicts an installation of an ATM System in Minneapolis along I-35W and an illustration of its deployment. DMS, known as lane control signals in this use, are installed on gantries over each lane of traffic that can display speeds of traffic upstream of the DMS to alert drivers of the reduced speeds by displaying advisory speeds. Signs can also alert drivers of traffic incidents to indicate whether certain lanes are closed to traffic, requiring a merge. Loop detection at half-mile intervals is used to detect vehicle speeds, which provides an advisory speed to traffic on lane control signals upstream. A similar ATM system has also been deployed in Seattle along segments of I-5, I-90, and SR 520. Instead of advisory speeds, however, speeds posted in Washington are enforceable speed limits. A formal evaluation of the effectiveness of these systems at reducing traffic incidents is currently underway.



Active Traffic Management Speed Warning System Deployment Overview

ATM System with Lane Merge Warning

ATM System with Lane Speed Warning

Source: Courtesy of Minnesota DOT

Figure 3-11. I-35W Minneapolis ATM System [14]

[14] Minnesota Department of Transportation. Smart Lanes. http://www.dot.state.mn.us/smartlanes/ Accessed on July 13th, 2012.

3.3.2 Current Infrastructure-Based Technologies Supporting Safety Applications

The systems identified in Section 3.3.1 depend on many different infrastructure-based technologies that are used either singularly or in combination with other technologies to produce the desired safety applications. These technologies include:

- RWIS/ESS
- Speed Detection
- Vehicle Classification Systems
- Driver-Infrastructure Interfaces.

Each of these technologies is discussed in greater detail below.

3.3.2.1 RWIS/ESS

This type of roadside infrastructure currently provides the operating agency, and often the traveling public, with information on the condition of roadway surfaces and environmental conditions on freeway and arterial roads. A RWIS comprises multiple ESS that measure atmospheric, pavement, and/or water level conditions in the field, along with a communication system for sending data to a central system for processing to support decision making by road operators and maintainers. Table provides statistics from the 2010 FHWA ITS Deployment Tracking Survey on the number of traffic management agencies that have deployed ESS along freeways and arterials.[15] The statistics indicate that ESS are widely deployed as roadside infrastructure and thus, have the potential to be utilized as providing inputs into an intersection warning system, similar to those described in Section 3.3.1 above.

Table 3-1. Number of Agencies with Operational Sensors and ESS Deployed as of 2010 (FHWA Survey)

	Freeway	Arterial
In-pavement sensors		
Agencies deploying in-pavement sensors to detect the condition of the pavement (i.e., temperature, moisture, etc.)	49	25
Weather data collected using Environmental Sensor Stations		
Number of agencies that deploy ESS for:		
Temperature	78	33
Humidity	73	24
Wind speed	73	28
Wind direction	70	--
Precipitation (rain)	67	29
Precipitation (snow)	53	19

[15] 2010 FHWA ITS Deployment Tracking Survey. Freeway information available at: http://www.itsdeployment.its.dot.gov/FM.aspx. Arterial information available at: http://www.itsdeployment.its.dot.gov/AM.aspx.

3.3.2.2 Speed Detection

This type of roadside infrastructure provides the operating agency and other roadside equipment with information on the speeds of vehicular traffic along freeway and arterial roadways. Table 3-2 provides statistics from the 2010 FHWA ITS Deployment Tracking Survey on the number of traffic management agencies and the quantity of speed detection components that have been deployed along freeways and arterials.[16] The statistics indicate that speed detection equipment is widely deployed as roadside infrastructure and thus, has the potential to be utilized as providing inputs into an intersection warning system, similar to those described in Section 3.3.1 above.

Loop stations and radar detectors are the primary types of detection equipment used to measure vehicle speeds and generate freeway travel time information.

Table 3-2. Number of Agencies and Speed Detection Equipment Deployed as of 2010 along Freeway and Arterial Roadways (FHWA Survey)

Freeway	Number of Agencies	Total Components Deployed
Loop stations used to collect real-time traffic data	49	12,465
Radar stations used to collect real-time traffic data	67	7,184
Video imaging detector stations	15	2,261
Toll tag readers	17	707
Arterial Roadway	**Number of Agencies**	**Number of Lane-Miles Deployed**
Agencies collecting travel time conditions in real time using roadside infrastructure devices such as loops, radar detectors, and video image detector systems	31	2,464

3.3.2.3 Vehicle Classification Systems

Vehicle classification systems can utilize basic roadside detectors to measure vehicles that exceed a certain dimensional threshold and help determine whether they may impact bridges or tunnels with low or narrow clearances. These types of systems could be utilized to provide drivers with advance notification in the vehicle of the potential height conflict, thus allowing them to take an alternate route around the bridge underpass. As of 2010, 28 traffic management agencies reported the use of an overheight warning system.[17]

More advanced vehicle classification systems have been deployed to meet other transportation objectives. The Florida DOT Office of Motor Carrier Compliance (OMCC) recently installed a Vehicle Dimension in Motion (VDIM) system at a weigh station along Interstate 4. As commercial vehicles use the entrance ramp to the weigh station, roadside equipment records a three-dimensional profile of the vehicle to determine if it exceeds recommended height, length, and

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[16] 2010 FHWA ITS Deployment Tracking Survey. Freeway information available at: http://www.itsdeployment.its.dot.gov/fm.aspx. Arterial information available at: http://www.itsdeployment.its.dot.gov/AM.aspx.

[17] 2010 FHWA ITS Deployment Tracking Survey. Available at: http://www.itsdeployment.its.dot.gov/FM.aspx.

width dimensions. If a commercial vehicle exceeds these dimensions, the system alerts OMCC staff on-site to inspect the vehicle for further investigation.[18] While this system has improved vehicle throughput at the station and enhanced commercial vehicle enforcement, it could be applied toward warning oversize vehicles of low clearance or tight width restrictions on bridges and tunnels.

3.3.2.4 Driver-Infrastructure Interface (DII)

This type of roadside infrastructure provides drivers with a visual warning or other message about traffic conditions or the presence of vehicles within or approaching an intersection. These warnings can be provided with text messages on DMS or with flashing lights installed on static warnings signs.

DMS. According to the 2010 FHWA ITS Deployment Tracking Survey cited previously, 105 traffic management agencies utilize DMS along freeways to provide messages to motorists. More than 4,000 DMS are in use throughout the country for freeway management purposes. While it is unknown how many DMS are used along arterial roadways to provide curve speed or intersection warnings to drivers, DMS technology is widely deployed and in use today to convey information to drivers.

Flashers. Detailed statistics are not maintained by FHWA on the use of flashers installed on static warning signs. The 2007 FHWA ITS Deployment Tracking Survey revealed at the time that six States had deployed intersection collision warning systems (ICWS) that used sensors to monitor traffic approaching dangerous intersections and then activate flashers to warn vehicles of approaching cross traffic.[19]

The same survey also revealed that 10 States had deployed warning systems with roadside detectors and electronic warning systems to warn drivers of dangerous speeds approaching freeway ramps, eight States had similar systems to warn drivers approaching curves on highways, and seven States had similar systems to warn drivers approaching downhill roadway grades.[20]

As of 2010, 27 traffic management agencies reported using Dynamic Curve Warning Systems among their freeway incident management strategies.[21]

While more recent statistics for intersection warning systems are not available since 2007, more States have come to utilize multiple types of sensors and infrastructure-based DII devices to provide visual warnings to drivers.

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[18] Traffic Technology International (2010) http://www.traffictechnologytoday.com/news.php?NewsID=19524. Accessed 07-20-2012.

[19] 2007 FHWA ITS Deployment Tracking Survey on Crash Prevention and Safety. Available at: http://www.itsdeployment.its.dot.gov/itspreviousyears/ResultsStateNational.asp?ID=1568&rpt=M&filter=1&year=2007

[20] 2007 FHWA ITS Deployment Tracking Survey on Crash Prevention and Safety. Available at: http://www.itsdeployment.its.dot.gov/itspreviousyears/ResultsStateNational.asp?ID=1571&rpt=M&filter=1&year=2007

[21] 2010 FHWA ITS Deployment Tracking Survey. Available at: http://www.itsdeployment.its.dot.gov/FM.aspx

3.3.3 Current Vehicle-Based Approach for Intersection and Corridor Safety

Presently there are no widely adopted onboard safety applications that address intersection, corridor, or tunnel/bridge safety, but as will be documented in the next section, there are many vehicle-based sensors and systems that are enabling technologies for future safety applications.

3.3.4 Current Vehicle-Based Technologies Supporting Safety Applications

The system identified in Section 3.3.3 depends on many different onboard technologies that are used either singularly or in combination with other technologies to produce the desired safety applications. These technologies primarily consist of vehicle-based sensors and vary by vehicle class and type. The following section identifies the commonly available data available for the various vehicle platforms.

3.3.4.1 Vehicle-Based Sensors

As an outcome of the technology insertion into vehicles, particularly as it relates to emissions and engine performance, nearly all vehicles have available various levels of onboard data communications between onboard systems and devices (vehicle telematics). Depending on their function and chassis type, these vehicles have a variety of data available for use by safety applications. The specific format and sensitivity of telematics data varies among manufacturers, but in general, the following data are available for each given vehicle class.

Passenger Vehicles

For passenger vehicles, telematics data serve two purposes, for intra-vehicle communication between components (such as engine to transmission), and for diagnostics. Of these data sources, only the emissions control diagnostics data are non-proprietary. The emissions related data source is referred to as the On Board Data II (OBD2) standard.[22] OBD2 operates over a standardized connector (SAE J1962), using one of five interface standards including IS0 15765, ISO 14320, ISO 9141-2, SAE J1850 VPW, and SAE J1850 PWM. Since 2008, all vehicles have been required to conform to ISO 15765. The diagnostic bus operates in a request-response mode, where any data delivered must be requested by the device interrogating it. As the diagnostics are tailored towards emissions control, most of the data that are available pertain to the operation of the engine. The data format is defined by SAE J1979; however the manufacturer is not required to make all sensors listed in the standard available. OBD2 data potentially useful for safety applications include:

- Throttle position
- Vehicle speed
- Engine revolutions per minute (RPM).

[22] SAE J2534, Recommended Practice for Pass-Thru Vehicle Programming

All modern cars have at least one CAN bus that interconnects all major electronic control units (ECUs) in the vehicle. The CAN bus data are proprietary to the manufacturer, but this is a high speed, low latency, broadcast data source that may be used to obtain data from the following sensors in addition to the OBD2 data sources:

- Wheel speed (individual or average)
- Steering angle
- Yaw rate
- Wiper status
- Light status
- Brake actuation
- Brake pressure.

Transit Vehicles

Transit vehicles often have internal intra-vehicle communications between components (such as engine to transmission), and external location data by automatic vehicle location (AVL) or automatic vehicle identification (AVI). The purpose of the AVL and AVI data is to monitor in-service transit vehicle locations to verify level of service, and to provide passengers with expected arrival times at stops. Because most transit buses are diesel powered, their intra-vehicle communication systems often conform to the SAE J1939 standard. The standard specifies that the CAN bus be used, operating at either 250 or 500kbps depending upon the standard revision. The standard specifies a broad number of data elements but manufacturers implement only a subset of available data. Some of the defined data elements include:

- Vehicle speed
- Wheel speed
- Steering angle
- Throttle position
- Brake actuation
- Brake pressure
- Engine RPM.

AVL and AVI data systems commonly consist of a recording device that performs location estimation via dead reckoning, beacons, or satellite navigation using a global positioning system (GPS). Some systems communicate short distances to receivers at bus stops, or long range via dedicated wireless links or a cellular network. The resolution of the location data and the amount of data available is highly dependent upon the implementation. In addition to location, the highest speed between time points or stops is often recorded.

Commercial Freight Vehicles

Freight vehicles typically have intra-vehicle communications between components, conforming to the SAE J1939 communications standard, and also utilize a GPS and wireless communication based vehicle tracking system for freight management. Tracking systems use either satellite or cellular communications or both. Vehicle location data are generally proprietary to a fleet because it pertains to competitive logistical efficiencies that freight operators have developed. Vehicle tracking location data are not collected frequently enough and with sufficient accuracy to support crash-imminent safety scenarios.

Public Safety Vehicles

Public safety vehicles encompass a variety of vehicle types, from passenger vehicles serving as police transportation to heavy diesel vehicles such as fire trucks and ambulances. Snow plows may also have data availability, depending upon the chassis types. In general, passenger and sport utility vehicle (SUV) sized vehicles will have onboard data systems comparable to passenger vehicles, while heavy vehicles will have onboard data systems conforming to the heavy equipment standard J1939.

Fleet Vehicles

Fleet vehicles such as taxis will often conform to passenger vehicle configurations, but will sometimes be augmented with AVL data to provide for efficient dispatching and monitoring. Such data may be considered proprietary.

3.4 Modes of Operation for the Current System or Situation

For each of the previously identified systems, a brief discussion of the modes of operation is included below.

3.4.1 Stop Sign Violation Warning (SSVW) Systems

Presently, there are no widely acceptable deployments of systems operating at stop signs that detect approaching vehicle speeds. Although experimental deployments have taken place, these have known faults such that these systems are still under development. Instead, it is more common for stop signs to be equipped with small flashing beacons on top or surrounding the border of the sign that flash on either a continuous basis or based on motion detected at a pre-set distance from the sign.

3.4.2 Rail Crossing Warning Systems

There are three general modes of operation for active rail crossing warning systems that include: 1) a default or standby mode in which warning devices are working properly and are not providing active warnings to drivers/pedestrians, 2) an active mode that warns drivers and pedestrians when a train has been detected approaching or occupying the crossing, and 3) a fail-safe mode in which the warning devices are activated when there are component failures or abnormal conditions in the system. In an active mode where a DMS is included in the system to provide additional warnings to drivers and pedestrians, the messages provided via DMS vary based on the operating agency's experience with determining the best type of message that can increase safety at the at-grade railroad crossing.

3.4.3 Spot Weather Information Warning (SWIW) Systems

There are three general modes of operation for SWIW Systems that include: 1) a default mode in which dynamic flashers/DMS are not active and are not providing a dynamic warning to drivers, 2) an active mode that warns drivers when spot weather conditions exceed safety thresholds for current conditions, and 3) a manual mode that can be activated by TMC staff to provide customized warnings to drivers about travel conditions. The messages provided to drivers can vary based on the available data and complexity of the algorithm used to assess spot weather thresholds. The modes of operation for the SWIW systems discussed earlier are summarized below.

VTrans RWIS Automation System

The default mode of operation for the VTrans RWIS Automation system is to keep the DMS blank if no inclement weather conditions are detected by RWIS equipment and pavement sensors on the roadway.

The active mode of operation is triggered when unsafe weather conditions have been detected along the roadway. RWIS equipment can detect the presence of fog on the roadway, while in-pavement sensors can detect pavement temperature, moisture, and whether the road has been treated with anti-icing chemicals. Central software at the TMC determines what messages to display from a pre-set library of warning messages.

A manual mode of operation for the DMS can also display a number of messages with an operator providing the override message directly to the DMS.

Virginia Department of Transportation Fog Warning System

The default mode of operation for the VDOT Fog Warning System is to blank out in-pavement LED lighting and the DMS if no fog is detected by ESS on the roadway.

The active mode of operation is triggered when fog conditions have been detected along the roadway. ESS can alert TMC staff of the intensity of fog on the roadway and then a decision can be made on activating in-pavement lighting and the appropriate DMS messages. ESS can also automate the in-pavement lighting and DMS messages if fog conditions are very intense.

California Department of Transportation Fog Detection and Warning System

The default mode of operation for the 3-line DMS that are installed in the Caltrans Fog Detection and Warning System is a blank message in which no fog is detected and visibility is greater than 800 feet.

The active mode of operation can provide different messages on the DMS based on the speeds detected and data gathered from visibility sensors. Messages can read “FOG/AHEAD” for conditions in which visibility is reduced to between 200 and 800 feet and “DENSE FOG/AHEAD” when visibility drops below 200 feet. In the event that wireless communications are lost with the TMC facility, and whenever visibility is reduced to less than 800 feet, different messages can be displayed based on detected speeds. When speeds are detected between 35 and 45 mph downstream, the message on the upstream DMS can read “FOG AHEAD/TRAFFIC SLOWS/TO 40 MPH.” In the event that traffic speeds drop below 5 mph, the message will display “STOPPED/TRAFFIC/AHEAD.” These messages are activated when vehicles are detected traveling between 20 and 75 mph on the roadway.

A manual mode of operation for the 3-line DMS can also display a number of messages with an operator providing the override message directly to the DMS. Table 3-3 displays the general decision process used in this system and the messages that are displayed on the DMS based on speed and visibility conditions.

Table 3-3. Caltrans Fog Detection and Warning System Messages Displayed Based on Speed and Visibility Conditions[23]

Priority	Conditions	Warning Message
0	No Fog and Visibility ≥ 800’	<BLANK>
1	Fog Detected, 200’≤ Visibility ≤ 800’, and Speed ≥ 45 mph	FOG AHEAD
2	Fog Detected, 0’≤ Visibility ≤ 200’, and Speed ≥ 45 mph	DENSE FOG AHEAD
3	Request from CHP and Speed ≥ 45 mph	DENSE FOG CHP PACE DO NOT PASS
4	Visibility ≤ 800’ and 35 mph ≤ Speed ≤ 45 mph and Loss of Center-to-Field Communications	FOG AHEAD TRAFFIC SLOWS TO 40 MPH
5	Visibility ≤ 800’ and 25 mph ≤ Speed ≤ 35 mph and Loss of Center-to-Field Communications	FOG AHEAD TRAFFIC SLOWS TO 30 MPH
6	Visibility ≤ 800’ and 15 mph ≤ Speed ≤ 25 mph and Loss of Center-to-Field Communications	FOG AHEAD TRAFFIC SLOWS TO 20 MPH
7	Visibility ≤ 800’ and 5 mph ≤ Speed ≤ 15 mph and Loss of Center-to-Field Communications	FOG AHEAD TRAFFIC SLOWS TO 10 MPH
8	Visibility ≤ 800’ and 0 mph ≤ Speed ≤ 5 mph and Loss of Center-to-Field Communications	STOPPED TRAFFIC AHEAD
9	Message Override from TMC Facility	<Message Varies>

Oregon Department of Transportation Butte Creek Ice Warning System

When unsafe travel conditions are not present, the default mode of operation for this system is to keep the flashing beacons on top of the static warning signs inactive.

An active mode of operation exists when the local ESS determines that a combination of pavement temperature, humidity, and moisture conditions have exceeded a pre-set threshold. This activates the flashing beacons on top of the static signs located at both ends of the corridor.

[23] Berman, Michael, Liu, John, and Justison, Liz. Caltrans Fog Detection and Warning System White Paper. Available at: http://gs.flir.com/uploads/file/white-papers/caltrans%20fog%20detection%20and%20warning%20system.pdf

Oregon Department of Transportation Flood Warning System

The default mode of operation for this system, with flashing beacons on top of static signs located on both ends of the corridor that is prone to flood conditions, provides no warning to drivers.

An active mode of operation exists when the on-site ESS determines that water has risen above a pre-set threshold. This activates the flashing beacons on top of the static signs located at both ends of the corridor.

3.4.4 Oversize Vehicle Warning (OVW) Systems

There are two general modes of operation for OVW Systems that include: 1) a default mode in which dynamic flashers/DMS are not active and are not providing a dynamic warning to oversize drivers, and 2) an active mode in which flashers/DMS are activated to provide an alert message when overheight vehicles are detected.

3.4.5 Reduced Speed Zone Warning (RSZW) Systems

The three types of speed warning systems described in Section 3.3.1.1 all include the use of dynamic warning signs to present radar or loop detected speeds, and all the systems have three basic modes of operation: 1) a default mode in which the DMS is not active (vehicles not present), 2) an active mode in which the speed of the vehicle is displayed when vehicles are detected approaching the DMS, and 3) an active mode in which the speed of the vehicle is emphasized (speed is flashing or is a different color) when vehicles are detected above the speed limit as they approach the DMS. Additional operating modes may be programmed by local authorities to meet local regulatory or policy issues, such as de-activating the DMS to prevent excessive speeding past the DMS.

3.5 User Classes and Other Involved Personnel

The systems described in this section support and are used by several user classes. The two primary user classes are vehicle operators and infrastructure providers. Additionally, user classes with secondary interactions with the various systems include non-motorized users and political, commercial, industrial, and social interest groups.

Vehicle Operators (Drivers)

Vehicle Operators include operators of all vehicle types and classes, including passenger, transit, commercial, fleet, public safety, and public service. These users are the primary beneficiaries of the proposed safety applications.

Infrastructure Provider

Other than in certain locales where private industry owns and/or operates toll facilities or screening applications, the majority of ITS infrastructure present today has been deployed and is maintained by various local and state public transportation departments. Traffic engineers and maintenance crews/technicians are the primary operators of these infrastructure systems. Traffic engineers design, develop, and implement these systems at intersections, curves, bridges, and other roadway locations. In many cases, communication network engineers are also necessary to maintain communication from the cabinet to a back office for monitoring and management purposes. Maintenance crews and technicians are responsible to configure signal timing plans within the controller; troubleshoot problems with cabinets, controllers, and sensors; and make minor adjustments to the signal timing plans. In the case of rail crossing warnings, railroad companies may play a role similar to that of transportation departments, functioning as owners and maintainers of certain infrastructure systems. In addition to private entities that own and/or operate toll facilities and screening applications, other providers may also play a role in providing support services. These other providers may include backhaul communication providers, resource sharing entities, and other roadside equipment owners among other systems.

Non-Motorized Users

Non-motorized users, which include both pedestrians and bicyclists, are a safety consideration at intersections, both signalized and unsignalized. These users have different operating characteristics and requirements than the operators of motorized vehicles, and are the most vulnerable class of intersection users.

Political, Commercial, Industrial, and Social Interest Groups

In any particular region, a number of political, commercial, industrial and/or social interest groups may influence (or desire to influence) how ITS components in a region operate. These might include, but are not limited to, political interest groups, businesses and commercial interest groups, special need interest groups, school groups and associations, neighborhood associations and civic organizations, the insurance industry, the research community, legal entities, and private land developers. While all such groups may not use the ITS information directly, the need to satisfy their concerns and requests can greatly influence the design and manner in which ITS technologies operate.

3.6 Support Environment

In general, ITS equipment, including those components identified above, are installed, operated, and maintained at the state or local level. Many of these agencies have their own trained staff, including traffic engineers and electricians to support setup, operation, and maintenance of the equipment; however, some rely on outside vendors to support their needs. The numbers and variety of trained personnel is dependent on the quantity and variety of equipment that is fielded, and as such, agencies tend to implement the same technologies and vendor equipment, when possible, across all similar installations.

Use of standards and the development of qualified parts lists (QPLs) and testing plans by many state and local agencies has also helped facilitate more efficient sourcing and maintenance of equipment. This approach also helps control maintenance costs by reducing the quantity and types of spares that must be provisioned.

4.0 Justification for and Nature of Changes

Connected vehicle applications offer tremendous promise for major improvements in highway safety. The connected vehicle and highway technologies function within a vehicle-to-vehicle (V2V) and V2I data communications platform that, like the Internet, supports numerous applications, both public and private. This high-speed wireless communications platform provides the foundation to integrate data from the infrastructure (presence of a train, for example) with data from the vehicle (such as speed) to assess likelihood of crash (by failing to stop at a railroad crossing, for example) and deliver more accurate and robust hazard warnings to drivers, thereby reducing the likelihood of a crash. V2I communications offer an environment rich in vehicle and infrastructure data that can be accessed and evaluated by the vehicles and drivers to improve safety and reduce fatalities and injuries. The data-rich environment offered by connected vehicle technologies can support a wealth of applications that can improve our highway and roadway safety, and the technologies are expected to help to substantially reduce the approximately 30,000 to 40,000 fatalities experienced each year on our roads and highways.[24]

USDOT has invested heavily in infrastructure-based safety technologies and countermeasure applications that improve highway safety. Recognizing the promise of the connected vehicle and connected highway technologies, USDOT, along with its State and local stakeholders, would like to develop key applications that integrate infrastructure and vehicle data to provide more robust and reliable alerts and warnings to drivers. Cooperative V2I systems have the advantage of collecting and sharing real-time data and warnings that are more likely to capture the attention of drivers due to their dynamic nature and improved reliability over static warning signs. They are also likely to be more cost effective than infrastructure-only or vehicle-only solutions.

This ConOps focuses on defining user needs for five applications that integrate roadside and vehicle information to provide the driver with real-time assistance and warnings.

4.1 Justification for Changes

The National Highway Traffic Safety Administration's (NTHSA) Fatality Analysis Reporting System (FARS) data shows that for 2010, there were a total of over 30,000 fatal crashes in the United States, making traffic-related incidents the most significant cause of preventable deaths in this country. The following crash-related statistics by application were found:

[24] NHTSA Traffic Safety Facts. Feb 2012. http://www-nrd.nhtsa.dot.gov/Pubs/811552.pdf

- SSVW: Approximately 6,700 fatalities in intersection area crashes occurred in the U.S. in 2009 with about 2,400 of those fatalities at signalized intersections.[25]
- RCVW: In 2011, there were about 1,963 total crashes at rail crossings in the U.S. with about 265 fatalities and 980 injuries.[26]
- SWIW: In 2010, for the entire US roadway network, 3,738 fatal crashes were attributable to adverse atmospheric or road surface conditions.[25] Note that spot weather impacts would be limited to select safety hotspots, such as mountain passes and low-lying areas.
- OVW: FHWA's National Bridge Inventory (NBI)[27] found collision damage when a vehicle or vessel hits a bridge is the third leading cause of bridge failure or collapse.[28]
- RSZW: Work zone statistics indicate that approximately 1,068 fatalities involving vehicle crashes in work zones occur each year.[29] Research has also shown that the highest proportion of child-car related collisions and fatalities occur in a 150 meter area around schools with 50 percent of these incidents occurring during the months and times of day when children are likely walking to and from school.[30]

Recent improvements in vehicle safety, infrastructure safety, increased driver awareness, and other factors have led to a reduction in fatalities, as a much welcomed trend. However, advanced V2I safety applications offer the potential to significantly improve warnings, passive safety countermeasures, and, eventually, active safety countermeasures to further mitigate and reduce collisions at intersections and single-vehicle incidents.

Current Deficiencies and Limitations

Currently, infrastructure-only and vehicle-only safety systems are in place to enhance safety independently. Integrating the data that is available from both infrastructure and vehicles can improve the driver's situational awareness and decision making, thereby reducing the likelihood of crashes.

The market penetration of connected technology in vehicles is expected to take on the order of a decade to achieve comprehensive deployment. Infrastructure deployed during this transition must continue to support the safety needs of non-equipped vehicles while leveraging the capabilities of connected vehicles to realize the safety benefits of V2I communications. As such, it is logical that the first generation of V2I safety applications builds upon current infrastructure systems for non-equipped vehicles, while at the same time providing data and information to connected vehicles to support better situational awareness and more informed decisions impacting safety.

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[25] Crash data from the Fatality Analysis Reporting System (FARS) Encyclopedia at: http://www-fars.nhtsa.dot.gov/Crashes/CrashesLocation.aspx.

[26] Crash data from the Federal Railroad Administration at: http://oli.org/about-us/news/collisions-casulties

[27] 600,000 bridges across the country have been registered in the NBI, see: http://www.fhwa.dot.gov/bridge/nbi.htm

[28] Bridge Vehicle Impact Assessment, Final Report, December 2011, University Transportation Research Center, New York State Department of Transportation

[29] Qi, Yi and Xin Chen, Lane Yang, Bin Wang, Lei Yu. Vehicle Infrastructure Integration (VII) Based Road-Condition Warning System for Highway Collision Prevention, Texas Southern University. May 2009.

[30] Grabowksi et. al., Distracted Drivers in School Zones: A National Report. Safe Kids USA. http://www.safekids.org/assets/docs/ourwork/research/distracted-drivers-report.pdf

4.2 Description of Desired Changes

The evolution of computer networks onboard vehicles and throughout the infrastructure provides a foundation for safety innovations that provide drivers with data and tools that improve their situational awareness and enable more informed decisions impacting safety. Applications that integrate roadside infrastructure and vehicle data can offer not only tremendous promise for enhancing safety, but at the same time, provide for benefits in mobility, in user convenience for the traveling public, and in reducing the environmental impact of highway travel.

The changes needed to support implementation of V2I connected vehicle applications are captured in the form of user needs. Following are six sets of user needs, one set common to all five identified safety applications (SSVW, RCWV, SWIW, OVW, RSZW) and a separate set for each application. The user needs have been articulated through the review of prior and current research, as well as the engagement of a limited set of stakeholders and subject matter experts. These user needs primarily focus on operational needs (or changes) but also include considerations for other needs/changes associated with interfaces, personnel, environment, and support.

4.2.1 User Needs Common to V2I Safety Applications

Table 4-1 lists user needs that are identified as being common to all five applications documented in this ConOps.

Table 4-1. Common User Needs

No.	Title	Description
UN-COM-001	Flexibility of System to Range of Drivers and Driver Capabilities	(Mandatory) The application needs to be flexible to take into account and adjust for the full range of drivers and their capabilities, including but not limited to inexperienced (e.g., teenaged) drivers, distracted drivers, and older drivers (e.g., slower reflexes, impaired hearing, loss of peripheral vision, diminished eyesight).
UN-COM-002	Affected Infrastructure	(Mandatory) The application needs to perform in and with existing infrastructure affected by a specific application.
UN-COM-003	Environmental Conditions	(Mandatory) The application needs to perform in all weather, road surface, and visibility conditions.
UN-COM-004	Performance Location	(Mandatory) The application needs to perform in urban, suburban, sub-rural, and rural areas.
UN-COM-005	Vehicle Position Accuracy	(Mandatory) The on-board application needs to provide lane-specific alerts and/or warnings when warranted
UN-COM-006	Interoperability with other Onboard Systems	(Mandatory) The application system needs to be interoperable and support integration with current onboard safety systems, with other future connected vehicle-enabled systems, and other future onboard safety systems.
UN-COM-007	False/Missed Alarms	(Mandatory) The application needs to operate with an acceptable level of false and missed alerts and/or warnings
UN-COM-008	Consideration of Human Factors	(Mandatory) The application needs to use alerts and/or warnings that are effective and compatible with automotive human factors guidelines, OEM driver-vehicle interface principles and practices, and driver-vehicle interfaces that follow human factor guidelines by the FHWA, NHTSA, and SAE.

Table 4-1. Common User Needs (Continued)

No.	Title	Description
UN-COM-009	Self-Diagnostics	(Mandatory) The application need a to provide periodic diagnostic self-testing including both onboard and infrastructure self-diagnostic tools, allowing a default mode that informs the driver (DVI and DII) when critical components are off-line.
UN-COM-010	Reporting Infrastructure Component Off-line Status	(Optional) The application needs to report the offline status of any of its infrastructure components to the owner/operator of that component if and when that component takes itself offline as the result of a self-diagnosed fault.
UN-COM-014	Minimization of Unauthorized Physical Access	(Mandatory) The application components need to minimize unauthorized physical access to the interfaces and components associated with the System of Interest.
UN-COM-015	Notification of Invasion	(Mandatory) The application should allow respective owners/operators of the vehicle or infrastructure components to know that unauthorized or unintentional physical access has occurred.
UN-COM-016	Communications Security	(Mandatory) The application communications between the vehicle and infrastructure systems need to have sufficient security to minimize unauthorized access (e.g., hacking) and to verify the authenticity of all messages.
UN-COM-017	Connected Vehicle Security Performance	(Mandatory) The connected vehicle security overhead shall not degrade the performance of the safety application
UN-COM-018	System upgrades	(Mandatory) System of Interest upgrades need to be compatible with and not adversely impact the performance of previous versions of the application.
UN-COM-019	Class of Roadway	(Mandatory) All applications need to perform for all functional classes of roadway and levels of service (LOS) where the application may be necessary.
UN-COM-020	Interoperability with other Infrastructure System	(Mandatory) The application system needs to be interoperable and support integration with current infrastructure safety systems, with other future connected vehicle-enabled systems, and other future infrastructure safety systems.
UN-COM-021	Integrity of the Infrastructure Application	(Mandatory) Infrastructure safety application alerts and/or warnings shall only be issued when real-time conditions are determined to warrant an advisory, alert or warning.
UN-COM-022	Maintenance	(Mandatory) Any roadside infrastructure is maintained by the agency, railroad or private-public partnership responsible for the roadway or railroad on which it is located. The agency or public-private partnership responsible for maintaining the roadway or railroad on which the equipment is installed is responsible for maintaining the equipment (either themselves or through a contractor operating on the agency's behalf).
UN-COM-023	Affected Vehicles	(Mandatory) The application needs to perform in and with vehicle classes and types affected by a specific application.
UN-COM-024	Integrity of the Vehicle Application	(Mandatory) Onboard safety application alerts and/or warnings shall only be issued when real-time conditions are determined to warrant an advisory, alert or warning.

4.2.2 User Needs Associated with the Stop Sign Violation Warning Application

Table 4-2 shows user needs specifically for the SSVW application, in addition to those identified in Table 4-1.

Table 4-2. Stop Sign Violation Warning User Needs[31]

No.	Title	Description
UN-SSVW-101	Application Deployment Location	(Mandatory) The SSVW Application needs to perform at all stop-controlled intersections, including at-grade rail crossings.
UN-SSVW-102	Onboard Notification	(Mandatory) The SSVW Application needs to alert and/or warn potential violators of the stop sign in time for the driver to take appropriate action.
UN-SSVW-103	DELETED	DELETED
UN-SSVW-104	Intersection Data Needs	(Mandatory) The SSVW Application needs data that accurately represents the physical intersection geometry and traffic control devices.
UN-SSVW-105	Road and Weather Condition Data Needs	(Optional) The SSVW Application needs data regarding weather and road conditions at the intersection.
UN-SSVW-106	Vehicle Based Data Needs	(Mandatory) The SSVW Application needs dynamic vehicle operating speed, telematics data and configuration data.
UN-SSVW-107	DELETED	DELETED
UN-SSVW-108	DELETED	DELETED

[31] The following user needs correspond to the SSVW scenario described in Section 6.1 of this ConOps.

4.2.3 User Needs Associated with the Railroad Crossing Violation Warning Application

Table 4-3 shows user needs specifically for the RCVW application, in addition to those identified in Table 4-1.

Table 4-3. Railroad Crossing Violation Warning User Needs[32]

No.	Title	Description
UN-RCVW-201	Application Deployment Location	(Mandatory) The RCVW Application needs to perform at all at-grade rail crossings, regardless of intersection geometries, number of tracks, skew, weather condition (visibility, road surface condition, etc.), area type (urban, suburban, sub-rural, or rural).
UN-RCVW-202	Onboard Notification	(Mandatory) The RCVW Application needs to alert and/or warn drivers of potential crash-imminent situations with an oncoming train or a train in the crossing in time for the driver to take appropriate action.
UN-RCVW-203	Intersection Data Needs	(Mandatory) The RCVW Application needs rail crossing geometry data.
UN-RCVW-204	DELETED	DELETED
UN-RCVW-205	Existing Signage	(Mandatory) The RCVW Application shall be in addition to existing traffic control devices.
UN-RCVW-206	Reference Frame	(Mandatory) The RCVW Application needs to use a prohibitive frame, which indicates a condition that may be unsafe.
UN-RCVW-207	Road and Weather Condition Data Needs	(Optional) The RCVW Application needs data regarding weather and road conditions.
UN-RCVW-208	Vehicle Based Data Needs	(Optional) The RCVW Application needs dynamic vehicle operating speed, telematics data and configuration data.
UN-RCVW-209	Train Presence	(Mandatory) The RCVW Application needs to have data regarding when approaching or crossing train(s) will cross and is crossing the RCVW-equipped at-grade crossing.
UN-RCVW-210	Train Based Data Needs	(Optional) The RCVW Application needs to have detection of an approaching and occupying train.
UN-RCVW-211	DELETED	DELETED
UN-RCVW-212	DELETED	DELETED
UN-RCVW-213	Train Occupy Time	(Optional) Application needs occupy time for crossing train(s) that will cross and is crossing the RCVW-equipped at-grade crossing.

[32] The following user needs correspond to the RCVW scenario described in Section 6.2 of this ConOps.

4.2.4 User Needs Associated with the Spot Weather Information Warning Application

Table 4-4 shows user needs specifically for the SWIW application, in addition to those identified in Table 4-1.

Table 4-4. Spot Weather Information Warning User Needs[33]

No.	Title	Description
UN-SWIW-301	Application Function	(Mandatory) The SWIW Application needs to perform for any location on the roadway network.
UN-SWIW-302	Road and Weather Condition Data Needs	(Mandatory) The SWIW Application needs data regarding weather and road conditions for targeted weather impact (e.g., visibility information for low visibility conditions)
UN-SWIW-303	Validation	(Mandatory) Recommended SWIW advisory messages, alerts or warnings need to be validated either automated with additional data comparison or manually.
UN-SWIW-304	Data needs	(Optional) SWIW may require infrastructure-based data on vehicle speeds
UN-SWIW-305	Vehicle Based Data Needs	(Optional) SWIW may require dynamic vehicle operating speed, telematics data and/or configuration data from the vehicle
UN-SWIW-306	Safe Speed Calculation	(Optional) SWIW may require a calculation of an appropriate speed for current weather conditions given a set of data elements: road geometry, environmental road conditions, visibility, flooding, vehicle speeds, vehicle configuration data, and available telematics. Any unavailable data will be given a previously determined default value in order to compute deceleration thresholds.
UN-SWIW-307	Reference Frame	(Mandatory) The SWIW Application needs to use a prohibitive frame, which indicates that a condition or speed may be unsafe.
UN-SWIW-308	Failure Mode	(Mandatory) The SWIW Application needs to have a failure mode that restores the roadway to default, static, regulatory signing already in place.
UN-SWIW-309	Consistency	(Mandatory) The SWIW Application needs to communicate the DII message to the vehicle such that consistent advisory messages, alerts and/or warnings may be displayed on the DVI.
UN-SWIW-310	Back Office Validation	(Mandatory) SWIW needs a connection to the back office to validate messages recommended by the infrastructure application

[33] The following user needs corresponds to the SWIW scenario described in Section 6.3 of this ConOps.

4.2.5 User Needs Associated with the Oversize Vehicle Warning Application

Table 4-5 shows user needs specifically for the OVW application, in addition to those identified in Table 4-1.

Table 4-5. Oversize Vehicle Warning Application User Needs[34]

No.	Title	Description
UN-OVW-401	Vehicle Notification	(Mandatory) The OVW Application needs to alert or warn potential violators of roadway clearance obstacles (e.g. low height bridges or and/or narrow tunnels) in time for the driver to take appropriate action. (e.g. alert in time to exit the roadway and/or warning in time to stop before impact)
UN-OVW-402	Vehicle Based Data Needs	(Mandatory) The OVW Application needs recent vehicle position and time history, time and position of infrastructure-based oversize vehicle measurements, and location and clearance of roadway obstacle (e.g. bridge/tunnel).
UN-OVW-403	Application Functionality By Obstacle Type	(Mandatory) The OVW Application needs to perform for all roadway clearance obstacle types.
UN-OVW-404	DELETED	DELETED
UN-OVW-405	Reference Frame	(Mandatory) The OVW Application needs to use a prohibitive frame, which indicates a condition that may be unsafe.
UN-OVW-406	Failure Mode	(Mandatory) The OVW Application needs to have a failure mode that restores the DII to default, static, regulatory signage or operational message (which could be a blank message).
UN-OVW-407	Notification of Oversize Vehicle Hazard	(Mandatory) The application needs to send a notification to applicable agencies in the event an oversize vehicle is detected passing beyond the last available exit.

[34] The following user needs corresponds to the OVW scenario described in Section 6.4 of this ConOps.

4.2.6 User Needs Associated with the Reduced Speed Zone Warning Application

Table 4-6 shows user needs specifically for the RSZW application, in addition to those identified in Table 4-1.

Table 4-6. Reduced Speed Zone Warning Application User Needs[35]

No.	Title	Description
UN-RSZW-501	Onboard Speed Notification	(Mandatory) The RSZW Application needs to warn vehicles driving above the posted reduced speed zone speed limit in time for the driver to take appropriate action
UN-RSZW-502	DELETED	DELETED
UN-RSZW-503	DELETED	DELETED
UN-RSZW-504	DELETED	DELETED
UN-RSZW-505	DELETED	DELETED
UN-RSZW-506	Infrastructure Failure Mode	(Mandatory) The RSZW Application needs to have a failure mode that restores the DII to default, static, regulatory signage.
UN-RSZW-507	DELETED	DELETED
UN-RSZW-508	Onboard Lane Configuration Notification	(Mandatory) The RSZW Application needs to warn vehicles impacted by changed roadway configurations in time for the driver to take appropriate action

4.3 Priorities Among Changes

Inputs from subject matter experts as well as inputs to USDOT from an American Association of State Highway and Transportation Officials (AASHTO) committee including State and local agency representatives identified the five applications described in this ConOps as "A priority," which led to their selection as the focus of this document. No specific prioritization among these applications has been made, nor has any unique distinction as mandatory or optional been made among the user needs.

4.4 Changes Considered but not Included

The approach used in articulating the ConOps for all five target applications focuses on the use of infrastructure components as a contributing element to achieve advanced safety capabilities in an equipped vehicle, while at the same time retaining or improving infrastructure-based safety capabilities for non-equipped vehicles. As such, the assumption was made that the applications must function in a mixed environment consisting of both equipped and non-equipped vehicles.

[35] The following user needs corresponds to the RSZW scenario described in Section 6.5 of this ConOps.

Additionally, these applications focus on alerting and/or warning the driver of the primary vehicle involved in any of the potential hazardous conditions or crash scenarios and do not provide alerts or warnings to secondary vehicles. For instance, in the case of SSVW, the application is only intended to assist the vehicle on the stop sign controlled minor road. Drivers of vehicles on the major road are not warned of the violating cross traffic on the minor road.

4.5 Assumptions and Constraints

As noted above in Section 4.4, the concepts for the V2I safety applications were defined with the following assumptions and constraints:

- The applications must support a mixed environment with both equipped and non-equipped vehicles
- The applications shall not interfere with current infrastructure-based systems, but shall build upon the architecture that already exists with current technologies.

5.0 Concepts for the Proposed System

This section describes the proposed V2I safety applications (SSVW, RCVW, SWIW, OVW, RSZW) developed in response to the user needs identified in Section 4. The application concepts discussed below are described as operational capabilities and are not intended to specify or imply particular technologies, designs, or implementations.

5.1 Background, Objectives, and Scope

This subsection provides an overview of the proposed applications, including each application's background, goals, objectives, and scope.

The deployment of each application will support:

- The development of a safety warning system that is deployable nationwide and found to be acceptable, understood, and useful to users, so as to elicit timely and appropriate driver response
- The development of a connected vehicle environment in which emerging technologies can utilize existing infrastructure to enhance safety benefits (eventually incorporating V2V concepts)
- The deployment of technology applications to establish a foundation of communication and technology systems that will bridge the gap between current roadway safety conditions with non-equipped vehicles and a saturated connected vehicle environment
- The institutional relationship between the public (e.g., U.S., state, and local DOTs) and private sectors (e.g., vehicle manufacturers) to further promote transportation safety.

5.1.1 Proposed Application: Stop Sign Violation Warning (SSVW)

The connected vehicle SSVW[36] safety application is a cooperative vehicle and infrastructure system that helps drivers avoid crashes at stop-controlled intersections by warning the vehicle driver that a stop sign violation is predicted to occur.

[36] Building on existing foundational research, this section has largely been excerpted from the "Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) Concept of Operations", v3.01 (2008) http://ntl.bts.gov/lib/38000/38600/38631/Appendix_B_CICAS-V_ConOps_Final_v0301_02-10-09__FHWA-JPO-10-068_.pdf, developed by the Crash Avoidance Metrics Partnership (CAMP) in conjunction with the Virginia Tech Transportation Institute for the ITS Joint Program Office and Research and Innovative Technology Administration, USDOT. Modifications have been made to the excerpted text that have not been approved, nor are necessarily supported, by CAMP or other contributors.

SSVW Background

There were about 6,700 fatalities in intersection area crashes in the U.S. in 2009 with about 2,400 of those fatalities at signalized intersection crashes.[37] While the SSVW application is presently envisioned to address only stop-controlled intersection violations, its implementation is expected to improve intersection safety for all drivers at signalized intersections. The primary deployment of this application is envisioned to be at higher speed intersections due to the increased likelihood for higher severity crashes.

An analysis of relevant National Highway Traffic Safety Administration (NHTSA) crash databases shows that violation crashes have a variety of causal factors. The SSVW application is intended to address the causal factors that include driver distraction;[38] and obstructed/limited visibility due to weather or intersection geometry. Driver warnings, such as those planned for SSVW, may prevent many violation-related crashes by alerting the distracted driver, thus increasing the likelihood that the driver will stop the vehicle before entering the intersection, and avoiding the crash.

A great deal of research has been conducted for the SSVW application under the name CICAS-V in a cooperative agreement program between the CAMP Vehicle Safety Communications 2 (VSC2) Consortium (Mercedes Benz Research and Development North America, Inc., Ford, GM, Honda and Toyota), along with the Virginia Tech Transportation Institute (VTTI), the ITS Joint Program Office (JPO) of the Research and Innovative Technology Administration (RITA), NHTSA, and the Federal Highway Administration (FHWA). This ConOps builds on this foundational CICAS-V research.

SSVW Goals and Objectives

As stated earlier, the goal of SSVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at intersections by warning the vehicle driver that a stop sign violation is predicted to occur. An equipped vehicle approaching an equipped intersection receives messages about the intersection geometry and if necessary, position correction information. The driver is issued a warning if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to violate the stop sign. While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the number of violations will decrease, and result in a decrease in the number and severity of crashes at unsignalized controlled intersections.

It is expected that this application might be most relevant for deployment at higher speed intersections, particularly for those that are modified to stop-controlled intersection where a different type of traffic control was previously used (e.g., traffic signal or yield sign). For this situation, the application might require a temporary RSE at the intersection to help ensure that all vehicles have the current data pertaining to this new form of traffic control, i.e., stop sign. It is believed that this would be a useful deployment of the SSVW application due to a presumed higher rate of incidents because of drivers who are familiar with the previous form of traffic control and unaware of the new stop sign configuration.

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[37] Crash data from the Fatality Analysis Reporting System (FARS) Encyclopedia at: http://www-fars.nhtsa.dot.gov/Crashes/CrashesLocation.aspx.

[38] Campbell, B.N. et al., *Analysis of Fatal Crashes.*

Specific goals of SSVW include the development of a cooperative V2I stop sign violation warning system that:

- Helps vehicle drivers avoid crashes due to violation of a stop sign
- Is effective at preventing stop sign violations, thereby reducing the number of fatal crashes, the severity of injuries, and the amount of property damage at SSVW intersections
- Is acceptable to users
- Is deployable throughout the United States.

Specific measurable objectives to support national deployment of the designed system associated with the above goals for SSVW include:

- Reduction in frequency and severity of crashes at SSVW intersections
    - Measures:
        - Direct: Reduction in crash frequency and severity
        - Surrogate: Reduction in stop sign violations
- A system that drivers understand and find useful, so as to elicit a timely and appropriate response from the driver
    - Measures: Effectiveness, user acceptance, understanding, and usability
- A system that displays information consistent with other relevant established safety countermeasures, e.g., information provided by a dynamic message sign
    - Measures: Effectiveness, user acceptance, understanding, and usability.

SSVW Vision

SSVW is intended to help a driver of an appropriately equipped vehicle approaching an appropriately equipped intersection to avoid crossing path crashes by warning the driver of an impending stop sign violation. Presently, the outcomes of the application's processing are envisioned to be limited to the vehicle running the application and only require a single equipped vehicle approaching a single equipped intersection at the proper time to achieve benefits of the system. This individual vehicle approach maximizes the probability of value being provided to drivers and DOTs, while simplifying deployment issues and logistics. The benefit to society increases with growing numbers of SSVW-equipped intersections and vehicles.

SSVW may also be seen as a step toward the deployment of initial infrastructure safety communications, such as reliable positioning and geospatial mapping techniques. Once these technologies are available and used by vehicles, they may enable other safety applications, including both V2I and V2V applications. SSVW can also serve to promote the development of institutional relationships among the vehicle manufacturers, third-party device manufactures, and the DOTs.

The initial implementation of the SSVW system and any later enhancements are intended to work with the connected vehicle architecture. With increased infrastructure-based sensing equipment and/or higher vehicle fleet penetration of connected vehicle technology, crashes beyond those caused by violations can be addressed, and enhanced crash avoidance systems can be implemented.

5.1.2 Proposed Application: Railroad Crossing Violation Warning (RCVW)

The connected vehicle RCVW safety application is a cooperative vehicle and infrastructure system that helps drivers avoid crashes at at-grade railroad crossings by warning the vehicle driver that a crash-imminent situation involving a crossing or approaching train is predicted to occur.

RCVW Background

There were about 1,963 total crashes at rail crossings in the U.S. in 2011 with about 265 fatalities and 980 injuries.[39]

An analysis of relevant NHTSA crash databases shows that these crashes have a variety of causal factors. The RCVW application is intended to address the causal factors that include driver distraction; obstructed/limited visibility due to weather or intersection geometry; or other vehicles. Driver warnings, such as those planned for RCVW, may prevent many railroad crossing-related crashes by alerting the distracted driver, thus increasing the likelihood that the driver will stop the vehicle before the at-grade crossing and avoid the crash.

RCVW Goals and Objectives

As stated earlier, the goal of RCVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at railroad crossings by warning the vehicle driver that a crash-imminent situation with a crossing or approaching train is predicted to occur. An equipped vehicle approaching an equipped crossing receives messages about the intersection geometry, presence of an approaching or crossing train, and if necessary, position correction information (e.g., lane level accuracy may be required for some situations, such as when a vehicle on an adjacent parallel roadway approach an intersection in a turn lane to turn toward the direction of an at-grade railroad crossing with a present or approaching train). The driver is issued a warning if the vehicle processing platform determines that, given current operating conditions, the driver is predicted to enter a crash-imminent situation with the approaching or crossing train. While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the number of violations will decrease, and result in a decrease in the number and severity of crashes at railroad crossings.

Specific goals of RCVW include the development of a cooperative vehicle-infrastructure railroad crossing violation warning system that:

- Helps vehicle drivers avoid crashes due to failure to yield for an approaching or crossing train
- Is effective at preventing railroad crossing violations, thereby reducing the number of fatal crashes, the severity of injuries, and the amount of property damage at RCVW intersections
- Is acceptable to users
- Is deployable throughout the United States.

[39] Crash data from the Federal Railroad Administration at: http://oli.org/about-us/news/collisions-casulties

Specific measurable objectives to support national deployment of the designed system associated with the above goals for RCVW include:

- Reduction in frequency and severity of crashes at RCVW intersections
    - Measures:
        - Direct: Reduction in crash frequency and severity
        - Surrogate: Reduction in railroad crossing violations
- A system that drivers understand and find useful, so as to elicit a timely and appropriate response from the driver
    - Measures: Effectiveness, user acceptance, understanding, and usability
- A system that displays information consistent with other relevant established safety countermeasures, e.g., information provided by a dynamic message sign
    - Measures: Effectiveness, user acceptance, understanding, and usability.

It should be noted that RCVW is not intended to address crashes associated with rail vehicles, such as light rail transit, that share a lane or parallel paths with vehicles on a street (e.g., light rail transit operations in mixed traffic). The complexities associated with multiple conflicts associated with vehicle turning paths that cross rail tracks in an urban setting for light rail transit, for example, are beyond the scope of this RCVW application. However, RCVW would apply to light rail transit at railroad crossings where light rail transit does not operate in mixed traffic (e.g., where it operates in a separate right-of-way).

RCVW Vision

RCVW is intended to help a driver of an appropriately equipped vehicle approaching an appropriately equipped railroad crossing to avoid crossing path crashes by warning the driver of an impending railroad crossing violation with an approaching or crossing train. Presently, the outcomes of the application's processing are envisioned to be limited to the vehicle running the application and only require a single equipped vehicle approaching a single equipped crossing at the proper time to achieve benefits of the system. This "single vehicle" approach maximizes the probability of value being provided to drivers and DOTs, while simplifying deployment issues and logistics. The benefit to society increases with growing numbers of RCVW equipped intersections and vehicles.

RCVW may also be seen as a step toward the deployment of initial infrastructure safety communications. Once these technologies are available and used by vehicles, they may enable other safety applications, including both V2I and V2V applications. RCVW can also serve to promote the development of institutional relationships between the vehicle manufacturers, third-party device manufacturers, Federal Rail Administration (FRA), Federal Transit Administration (FTA), railroad companies, and the DOTs.

The initial implementation of the RCVW system and any later enhancements are intended to work with the connected vehicle architecture.

With increased infrastructure-based sensing equipment and/or higher vehicle fleet penetration of connected vehicle technology, crashes beyond those caused by violations can be addressed, and enhanced crash avoidance systems can be implemented.

5.1.3 Proposed Application: Spot Weather Impact Warning (SWIW)

The connected vehicle SWIW safety application is a cooperative vehicle and infrastructure system that helps drivers avoid crashes in areas prone to adverse weather impacts that could cause crash imminent scenarios if appropriate precautions are not taken. Specifically, SWIW is intended to address hazardous driving conditions caused by low visibility, adverse surface conditions, flooding, and high winds.

SWIW Background

Numerous crashes are caused, at least in part, by adverse weather conditions. In 2010, for the entire US roadway network, 3,738 fatal crashes were attributable to adverse atmospheric or road surface conditions.[25] Specifically, atmospheric conditions contributed to 306 fatalities attributable to reduced visibility caused by fog, smog, smoke, or blowing sand, soil, or dirt; 41 to severe crosswinds; and 2,589 to precipitation including rain, sleet, hail, snow, or blowing snow. Also, 50 fatalities were attributable to adverse roadway surface conditions categorized as standing or moving water.

Note that spot weather impacts would be limited to select safety hotspots, such as mountain passes and low-lying areas. Specifically, many locales have areas prone to adverse weather conditions such as high altitude mountain passes prone to fog or ice not found as frequently at lower elevations on the same roadway, or flooding in low-lying areas. Driver warnings, such as those planned for SWIW, may prevent many weather-related crashes in these areas by alerting the driver of adverse weather, along with possible information for advisory or enforceable reduced speeds and/or recommendations for seeking an alternate route, thus increasing driver awareness and the likelihood that the driver will avoid a crash-imminent scenario.

SWIW Goals and Objectives

As stated earlier, the goal of SWIW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes in areas prone to adverse weather impacts by warning the vehicle driver that a crash-imminent situation is possible, particularly in extreme situations where precautions are not taken, such as reducing speed or seeking an alternate route. The infrastructure application will collect available infrastructure and vehicle data, most importantly from RWIS and process available data to recommend an appropriate advisory message, alert, and/or warning. Depending upon the availability of data for validation (e.g., redundant RWIS data source, traffic speeds, etc.), validation of the recommended message may be needed from a back office TMC before the message is posted on the DII. An equipped vehicle approaching an equipped roadway segment will receive a message that includes data regarding the message posted on DII; length of adverse weather impact zone [throughout which the driver-vehicle interface (DVI) message should apply]; weather data collected by RWIS; and, if available, the advisory, enforceable speed, and/or diversion to an alternate route as recommended by the infrastructure application. The driver is issued an advisory message, alert, or warning if the vehicle processing platform determines that, given current operating conditions, a crash-imminent situation is likely to occur due to the weather impacts, and notifies the driver if reduced speed or an alternate route is recommended.

While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the driver awareness will increase, and result in a decrease in the number and severity of crashes at high-risk adverse weather locations.

Specific goals of SWIW include the development of a cooperative vehicle-infrastructure spot weather warning system that:

- Helps increase vehicle driver awareness of current adverse spot weather conditions, thereby reducing crashes caused by low visibility, adverse surface conditions, flooding, and high winds
- Is effective at informing drivers to adverse weather and/or the need to reduce speed or divert, thereby reducing the number of fatal crashes, the severity of injuries, and the amount of property damage at high-risk adverse weather locations
- Is acceptable to users
- Is deployable throughout the United States.

Specific measurable objectives to support national deployment of the designed system associated with the above goals for SWIW include:

- Reduction in frequency and severity of crashes at high-risk adverse weather locations
    - Measures:
        - Direct: Reduction in crash frequency and severity
        - Surrogate: Reduction in speed during adverse weather conditions
- A system that drivers understand and find useful, so as to elicit a timely and appropriate response from the driver
    - Measures: Effectiveness, user acceptance, understanding, and usability
- A system that displays information consistent with other relevant established safety countermeasures, e.g., information provided by a dynamic message sign
    - Measures: Effectiveness, user acceptance, understanding, and usability.

Although SWIW may include guidance for recommended advisory or enforceable speed, it is not intended to include vehicle-to-vehicle communications or tracking capabilities to provide direct and specific crash-imminent situations with other vehicles (i.e., this would be covered under a separate forward collision warning application).

SWIW Vision

SWIW is intended to help a driver of both non-equipped and equipped vehicles approaching an area prone to adverse weather impacts that could cause crash-imminent scenarios if appropriate precautions are not taken. Presently, the outcomes of the application's processing are envisioned to be limited to the vehicle running the application and only require a single equipped vehicle approaching a single equipped crossing at the proper time to achieve benefits of the system. This "single vehicle" approach maximizes the probability of value being provided to drivers and DOTs, while simplifying deployment issues and logistics. The benefit to society increases with growing numbers of SWIW equipped roadways and vehicles.

The initial implementation of the SWIW system and any later enhancements are intended to work with the connected vehicle architecture.

5.1.4 Proposed Application: Oversize Vehicle Warning (OVW)

The connected vehicle OVW safety application is a cooperative vehicle and infrastructure system that helps drivers of oversize vehicles avoid collisions with roadway clearance obstacles (e.g., low height and/or narrow horizontal clearance bridges or tunnels). The system provides an alert and/or a warning to vehicle drivers that a roadway clearance obstacle is approaching.

OVW Background

Bridge and tunnel collisions are a common occurrence that may result in serious damage and loss of life. However, few studies have focused on why collisions occur or how to mitigate them. There is little data available on bridge and tunnel incidents. FHWA's NBI[40] found that the third leading cause of bridge failure or collapse is collision damage when a vehicle or vessel hits a bridge.[41] A study conducted on overheight vehicle bridge collisions across Maryland[42] found that standard bridge clearance is between 14 and 17 feet and that the frequency of bridge hits peak for heights of 14.5 feet (the vertical clearance commonly used over local roads) and 16.5 feet (the vertical clearance over Interstate and State routes). The study also noted that States view overheight bridge collisions to be a significant problem, although few states collect data on bridge hits.

The Maryland Study also found that states do not uniformly post clearance warnings. Some states post actual vertical clearance warning signs, while other states under report clearance heights by up to 12 inches. This under reporting can result in vehicles ignoring clearance warnings, since the vehicle driver knows that the bridge clearance has been under reported. A study on bridge hits in the United Kingdom found that the three main causes of bridge hits include: (1) drivers not knowing the height of their vehicles/cargo, (2) lack of provision of alternative routes around low bridges, and lack of planning of routes by haulers, and (3) inadequate signing at and on the approach to low bridges.[43] Other factors for bridge hits include: lack of signs, distraction, positioning of signs, driver cognizance, and bumpy road conditions. One study found that regardless of bridge characteristics, drivers are increasingly cautious in their decision making the closer they get to a bridge.[44]

In an effort to reduce bridge hits, some States have introduced mitigation measures including: installing more signs posting clearances on or in advance of bridges, increasing the vertical clearance of bridges, and installing overheight detection systems. Specifically, early warning detection systems (EWDS) are used that may include laser systems and infrared systems. While these systems have been noted to reduce collisions, they are still subject to operational issues

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[40] 600,000 bridges across the country have been registered in the NBI.

[41] Bridge Vehicle Impact Assessment, Final Report, December 2011, University Transportation Research Center, New York State Department of Transportation

[42] Fu, C.C. (2001). Maryland Study, Vehicle Collision with Highway Bridges. Contract No. SP907B1, Maryland State Highway Administration, The Bridge Engineering Software and Technology Center, Department of Civil Engineering, University of Maryland and Fu, C.C., Burhouse, J.R. and Chang, G.-L. (2003), "Study of Overheight Vehicles with Highway Bridges", Transportation Research Board.

[43] Martin, A. and Mitchell, J. (2004), Measures to Reduce the Frequency of OverHeight Vehicles Striking Bridges: Final Report, Unpublished Report, PPAD9/100/61, Department of Transport, U.K.

[44] Horberry, T., Halliday, M. and Gale, A.G. (2002), "Bridge Strike Reduction: Optimizing the Design of Markings", Accident Analysis and Prevention 34 (2002) 581–588.

such as false detection (from antennas, debris, birds, and snow deposits on top of trucks) and the misalignment of the lasers.[45]

OVW Goals and Objectives

As stated earlier, the goal of OVW is to provide a cooperative vehicle and infrastructure system that helps drivers of oversize vehicles avoid collisions with roadway clearance obstacles by alerting and/or a warning the driver as they approach the roadway clearance obstacle. An equipped vehicle on a stretch of road ahead of a roadway clearance obstacle (e.g., low- or narrow clearance bridge or tunnel) is issued an alert (and if necessary a warning) if the vehicle application determines that, given the current height and width of the vehicle (as measured by the roadside infrastructure), the driver will not clear the obstacle. While the system may not prevent all collisions through such alerts/warnings, it is expected that, with an effective alert/warning, the number of oversize vehicles driving through these roadway clearance obstacles will decrease, and result in a decrease in the number and severity of collisions.

Specific goals of OVW include the development of a cooperative vehicle-infrastructure collision warning system that:

- Helps vehicle drivers avoid crashes due to roadway clearance obstacles (e.g., low height and/or narrow horizontal clearance bridges or tunnels)
- Is effective at preventing oversize vehicle collisions, thereby reducing the number of fatal crashes, the severity of injuries, and the amount of property damage at roadway clearance obstacles
- Is acceptable to users
- Is deployable throughout the United States.

Specific measurable objectives to support national deployment of the designed system associated with the above goals for OVW include:

- Reduction in frequency and severity of crashes at roadway clearance obstacles (e.g., low height and/or narrow horizontal clearance bridges and tunnel)
  - Measures:
    - Reduction in oversize vehicle collisions with roadway clearance obstacles
- A system that drivers understand and find useful, so as to elicit a timely and appropriate response from the driver
  - Measures: Effectiveness, user acceptance, understanding, and usability
- A system that displays information consistent with other relevant established safety countermeasures, e.g., information provided by a dynamic message sign
  - Measures: Effectiveness, user acceptance, understanding, and usability.

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[45] Bridge Vehicle Impact Assessment, Final Report, December 2011, University Transportation Research Center, New York State Department of Transportation

OVW Vision

OVW is intended to help drivers of both equipped and non-equipped oversize vehicles avoid collisions with roadway clearance obstacles (e.g., low height and/or narrow horizontal clearance bridges and tunnels). Presently, the outcomes of the application's processing are envisioned to be limited to the approaching roadway clearance obstacle or consecutive roadway clearance obstacles and require two sets of roadside infrastructure for a two-stage alert/warning system. The application includes in-vehicle GPS and lane level accuracy, enabling the tracking of multiple oversize vehicles traveling along a route. The scope of this application is a single vehicle warning to prevent crash-imminent scenarios.[46] The longer term vision for this application includes warnings that span multiple roadway clearance obstacles along with the development of a database of roadway infrastructure clearance data that may be utilized by an OVW vehicle application when processing clearance levels and determining the need for an alert or warning.

The initial implementation of the OVW system and any later enhancements are intended to work with the connected vehicle architecture.

5.1.5 Proposed Application: Reduced Speed Zone Warning

The connected vehicle RSZW safety application is a cooperative vehicle and infrastructure system that helps drivers avoid crashes in reduced speed zones by warning the vehicle driver that they are operating at a speed higher than the zone's posted speed limit and/or providing information regarding changes in roadway configuration (e.g., lane closures, lane shifts).

RSZW Background

Reduced speed zones include (but are not be limited to) construction/work zones, school zones, and incorporated zones (e.g., rural towns). Collisions in reduced speed zones may be attributed to several factors including a driver's inability to see the impending reduced speed zone and the differences in speed between the zone and the surrounding area.[47] One factor related to reduced speed zone safety is the discontinuity in travel caused by the reduced speed zones. This is particularly relevant in work zones.

Work zones not only introduce reductions in speed, but also reductions in the numbers of lanes and/or lane width available for vehicles, detours, delays, road closures, and other similar aspects.[48] Research has also found that the numbers and impacts of work zones are increasing. Many of the nation's roadways are nearing the end of their targeted life cycle and must be placed into reconstruction and rehabilitation. While the number, duration, and length of work zones

[46] Routing applications for oversize/overweight vehicles would be expected to be part of specialized navigation software.

[47] WTI. (April 2010) IntelliDrive[SM] Rural Risk Warning System (IRRWS): A North/West Passage Rural Vehicle Infrastructure Integration Demonstration Project Final Report. Western Transportation Institute (WTI) College of Engineering, Montana State University. April 2010 and Qi, Yi and Xin Chen, Lane Yang, Bin Wang, Lei Yu. Vehicle Infrastructure Integration (VII) Based Road-Condition Warning System for Highway Collision Prevention, Texas Southern University. May 2009

[48] Kumar, Manjunathan and Doug Galarus, Sean Graham, Christopher Strong, Evaluation of ITS Technologies in Rural Work Zones, Final Report. Western Transportation Institute, College of Engineering, Montana State University. April 2006.

continues to increase, so do the active travel demands on the associated roadways.[49] The resulting delays are another safety concern. Delays can increase driver stress and frustration, potentially affecting driver behavior within and around work zones that may impact the safety of workers and other motorists.[50] Work zone statistics indicate that approximately 1,068 fatalities involving vehicle crashes in work zones occur each year. In addition, work zone accident related property damages have been estimated at approximately $3,687 per crash.[51]

School zones are another reduced speed zone focus area. Speeding is considered one of the major causes of frequent and severe traffic accidents occurring in school zones.[52] Research has shown that the highest proportion of child-car related collisions and fatalities occur in a 150 meter area around schools with 50 percent of these incidents occurring during the months and times of day when children are likely walking to and from school.[53] The RSZW safety application is intended to mitigate the potential for speed-related safety issues in and around reduced speed zones.

RSZW Goals and Objectives

As stated earlier, the goal of the RSZW is to provide a cooperative vehicle and infrastructure system that helps drivers avoid crashes in reduced speed zones by warning the driver that they are operating at a speed higher than the zone's posted speed limit and/or providing information regarding changes in roadway configuration (e.g., lane closures, lane shifts), particularly for a crash imminent scenario requiring a lane change. An equipped vehicle on a stretch of road ahead of a reduced speed zone is issued an alert (and if necessary a warning) if the vehicle application determines that, given the current vehicle speed and approaching reduced speed zone roadway configuration (as provided by the roadside infrastructure), the driver is at risk of an incident based on his or her current speed or changes in the roadway. Similarly, an unequipped vehicle is issued an alert (and if necessary a warning) if the infrastructure application determines that, given the current vehicle speed and approaching reduced speed zone roadway configuration, the driver is at risk of an incident. While the system may not prevent all collisions through such alerts/warnings, it is expected that, with an effective alert/warning, driver awareness of reduced speed zones will increase, and result in a decrease in the number and severity of crashes at or approaching such zones.

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[49] GTI (January 2005) Final Report: Evaluating Speed Reduction Strategies for Highway Work Zones (Smart Work Zones). Georgia Transportation Institute, Georgia Institute of Technology.

[50] Kumar, Manjunathan and Doug Galarus, Sean Graham, Christopher Strong, Evaluation of ITS Technologies in Rural Work Zones, Final Report. Western Transportation Institute, College of Engineering, Montana State University. April 2006.

[51] Qi, Yi and Xin Chen, Lane Yang, Bin Wang, Lei Yu. Vehicle Infrastructure Integration (VII) Based Road-Condition Warning System for Highway Collision Prevention, Texas Southern University. May 2009.

[52] Lee, C., Sangsoo Lee, Bongsoo Choi, and Youngtae Oh, Effectiveness of Speed-Monitoring Displays in Speed Reduction in School Zones. Transportation Research Board of The National Academies. 2006.

[53] Grabowksi et. al., Distracted Drivers in School Zones: A National Report. Safe Kids USA. http://www.safekids.org/assets/docs/ourwork/research/distracted-drivers-report.pdf

Specific goals of RSZW include the development of a cooperative vehicle-infrastructure collision warning system that:

- Helps increase vehicle driver awareness of reduced speed zones, thereby reducing crashes caused by speeding and/or a lack of familiarity with the changed roadway configuration
- Is effective at alerting drivers to the need to reduce speed and/or changes in the roadway configuration reducing the number of fatal crashes, the severity of injuries, and the amount of property damage at or approaching reduced speed zones
- Is acceptable to users
- Is deployable throughout the United States.

Specific measurable objectives to support national deployment of the designed system associated with the above goals for RSZW include:

- Reduction in frequency and severity of crashes at or approaching reduced speed zones
  - Measures:
    - Direct: Reduction in crash frequency and severity
    - Surrogate: Reduction in speed at a reduced speed zone
- A system that drivers understand and find useful, so as to elicit a timely and appropriate response from the driver
  - Measures: Effectiveness, user acceptance, understanding, and usability
- A system that displays information consistent with other relevant established safety countermeasures, e.g., information provided by a dynamic message sign
  - Measures: Effectiveness, user acceptance, understanding, and usability.

RSZW Vision

RSZW is intended to help drivers of both equipped and non-equipped vehicles driving above the approaching reduced speed zone posted speed limit, which could cause crash imminent scenarios if appropriate precautions are not taken. Presently, the outcomes of the application's processing are envisioned to be limited to the vehicle running the application and only require a single equipped vehicle approaching a reduced speed zone at the proper time to achieve benefits of the system. This "single vehicle" approach maximizes the probability of value being provided to drivers and DOTs, while simplifying deployment issues and logistics. The benefit to society increases with growing numbers of RSZW-equipped roadways and vehicles.

The initial implementation of the RSZW system and any later enhancements are intended to work with the connected vehicle architecture.

5.2 Operational Policies and Constraints

The subsections below describe the operational policies and constraints that apply to the proposed applications, with the recognition that they are likely to evolve as the application is further developed and deployed. The following lists are numbered for reference only and do not represent a priority order.

Operational policies are defined by the IEEE 1362 standard as "predetermined management decisions regarding the operation of the new or modified system, normally in the form of general statements or understandings that guide decision-making activities. Policies limit decision-making freedom, but do allow for some discretion."

Operational constraints are defined by the IEEE 1362 standard as "limitations placed on the operations of the proposed system." Some of these constraints may also represent functional requirements, which will be specified in the requirements documentation.

5.2.1 Common Operational Policies and Constraints for All Proposed Applications

Operational Policies

OP-COM-01. For all applications herein, the application will be capable of using the emerging Connected Vehicle technologies, as defined by USDOT, as its enabling foundation

OP-COM-02. For all applications herein, any vehicle with an onboard application implemented will be able to inform the driver when the onboard application has degraded status.

OP-COM-03. For all applications herein, for any shared means of communication, messaging standards will allow assigning priorities to messages such that crash imminent messages will have priority over non-safety-enhancing messages. The messaging necessary to fulfill these applications shall follow the message priority approach as recommended in Annex A of SAE J2735:2009 or the current standard.

OP-COM-04. For all applications herein, the integrity of the data provided by the enabled infrastructure shall be maintained.

OP-COM-05. For all applications herein, the functioning of the application shall not violate existing federal, state, or local agency, or rail industry, policies.

OP-COM-06. For all applications herein, minimal training is required for drivers to use the application. When possible, the interface solutions use stereotypical coding of information (color, frequency, symbols) to ensure meaningful communication with the driver and to ensure that required actions are intuitive in order to increase understanding by drivers with minimal exposure. Although it is hoped that this will reduce the need for training, some driver education may be warranted.

OP-COM-07. For all applications herein, any infrastructure components are available to transmit the required information to vehicles 24 hours a day.

OP-COM-08. For all applications herein, any roadside infrastructure is maintained by the agency or private-public partnership responsible for the roadway or railroad on which it is located. The agency or public-private partnership responsible for maintaining the roadway on which the equipment is installed is responsible for maintaining the equipment (either themselves or through a contractor operating on the agency's behalf).

OP-COM-09. For all applications herein, in-vehicle warning decisions are made by the vehicle, with the infrastructure only providing data for the vehicle to make the decision.

Operational Constraints

OC-COM-01. Not all roadways will be equipped nor will they necessarily implement all connected vehicle V2I safety application capabilities. This is due to the magnitude of the roadway network and the time and cost associated with installing necessary infrastructure equipment. Even if some connected vehicle applications are in place in an area, the roadside equipment may not provide sufficient data needed to support all applications. State and local DOTs, in cooperation with the USDOT, must determine which roadways warrant specific applications and prioritize their installation.

OC-COM-02. For all applications herein, there are a limited number of and limited locations for roadside infrastructure. Due to restricted financial resources, State and local DOTs, and private partners, in cooperation with the USDOT, must determine the number of and the location of specific connected vehicle V2I safety application installations. This decision will be based on several factors, which include (but are not limited to): pre-existing infrastructure, retrofit capabilities, historic collision statistics, and collision potential.

OC-COM-03. For all applications herein, not all vehicles will be equipped with an onboard application platform. It is understood that an initial deployment will only impact connected vehicles, and that a 100% connected environment will take many years to occur.

OC-COM-04. For all applications herein, the driver-vehicle interface and/or driver-infrastructure interface may not be uniform. The warning provided to the driver may vary between vehicle models, OBE suppliers, and deployments.

OC-COM-05. All applications herein will be limited by the amount of data available. Customization for individual driving habits, for example, will not be required for initial deployment. As data becomes available to the application over time, algorithms will be enhanced to include all available, relevant information.

5.2.2 Proposed Application: Stop Sign Violation Warning (SSVW)

Operational Policies

OP-SSVW-01. Moved to common section. DELETED.

OP-SSVW-02. SSVW will not require automatic braking. However, brake assist (i.e., pre-charging the brakes in anticipation of the driver using them) may be considered as part of the initial prototyping and testing. Test results will determine whether this function remains as part of an initially deployable application.

OP-SSVW-03 . Moved to common section. DELETED.

OP-SSVW-04. SSVW will not require the application to recognize the presence of pedestrians, bicyclists, and other vehicles moving in and around the intersection. Pedestrians may benefit, but SSVW has no specific countermeasure(s) to protect pedestrians, bicyclists, or other vehicles.

OP-SSVW-05. Moved to common section. DELETED.

OP-SSVW-06. Moved to common section. DELETED.

OP-SSVW-07. Moved to common section. DELETED.

OP-SSVW-08. DELETED.

OP-SSVW-09. Moved to common section. DELETED.

OP-SSVW-10. Moved to common section. DELETED.

OP-SSVW-11. DELETED.

OP-SSVW-12. The SSVW application does not interfere with or supplant existing traffic control devices.

OP-SSVW-13. Inserted as a common user need. DELETED.

OP-SSVW-14. Safe deceleration determination is made by the vehicle and not the infrastructure. The infrastructure is only capable of providing roadside data to the vehicles traveling into the upcoming stop-controlled intersection.

OP-SSVW-15. DELETED.

OP-SSVW-16. DELETED.

Operational Constraints

OC-SSVW-01. Moved to common section. DELETED.

OC-SSVW-02. Moved to common section. DELETED.

OC-SSVW-03. Not all vehicles will be SSVW equipped. It is understood that an initial deployment will only impact connected vehicles, and that a 100% connected environment will take many years to occur.

OC-SSVW-04. Moved to common section. DELETED

OC-SSVW-05. The SSVW application is single-vehicle based and does not require the detection of or communication with other vehicles. The SSVW application accounts only for the equipped vehicle. The application does not require accounting for other vehicles on the roadway. SSVW does not require providing warnings of an impending crash with other vehicles. This information may be addressed through other applications.

OC-SSVW-06. Moved to common section. DELETED.

OC-SSVW-07. The minor road driver is only provided assistance in decision-making. Regulatory signs at the intersection control traffic flow; the SSVW application only assists the minor road driver in obeying traffic laws. The interface solutions are targeted toward the minor road driver and it is assumed that the minor road driver is responsible for any crash that would occur. Improving the decision making of minor road drivers regarding awareness of the stop-controlled intersection will therefore reduce the likelihood that the same type of crash occurs. Alerts and warnings to major road drivers could be provided with a separate safety application about violating minor road vehicles entering or crossing the major road vehicle path.

OC-SSVW-08. Some nuisance alarms may be expected and exempted. It is expected that some situations involving law enforcement or emergency vehicles may require these or other SSVW-equipped vehicles to enter an SSVW-equipped intersection without stopping. In this event, it is expected that a “nuisance” warning would be issued by the SSVW application that the driver would understandably and necessarily disregard (as with the stop sign itself, given emergency circumstances).

5.2.3 Proposed Application: Railroad Crossing Violation Warning (RCVW)

Operational Policies

OP-RCVW-01. Moved to common section DELETED.

OP-RCVW-02. RCVW will not require automatic braking. However, brake assist (i.e., pre-charging the brakes in anticipation of the driver using them) may be considered as part of the initial prototyping and testing. Test results will determine whether this function remains as part of an initially deployable application.

OP-RCVW-03. Moved to common section DELETED.

OP-RCVW-04. Moved to common section DELETED.

OP-RCVW-05. Moved to common section DELETED.

OP-RCVW-06. Moved to common section DELETED.

OP-RCVW-07. DELETED.

OP-RCVW-08. Moved to common section DELETED.

OP-RCVW-09. Moved to common section DELETED.

OP-RCVW-10. DELETED.

OP-RCVW-11. The RCVW application responds to every train. The application is capable of reliably identifying and monitoring every train as it approaches the crossing.

OP-RCVW-12. Inserted as a common user need. DELETED.

OP-RCVW-13. The roadway users will be mixed, including equipped and non-equipped vehicles. Roadway users will include equipped and non-equipped vehicles. Non-equipped vehicles will rely on existing signage and/or warning devices to safely navigate the railroad crossing. Non-equipped vehicles will not have access to onboard application components.

OP-RCVW-14. Safe deceleration determination is made by the vehicle and not the infrastructure. The infrastructure is only capable of providing roadside data to the vehicles traveling into the upcoming railroad crossing intersection. While this does not preclude the infrastructure from displaying a general warning, only the equipped vehicle would present vehicle-specific safe speed.

OP-RCVW-15. RCVW will not require the application to recognize the presence of pedestrians, bicyclists, and other vehicles moving in and around the intersection. Pedestrians may benefit, but RCVW has no specific countermeasure(s) to protect pedestrians, bicyclists, or other vehicles.

OP-RCVW-16. DELETED

OP-RCVW-17. Application does not impede trains on intersecting railroad. The RCVW application should not impact the speeds or passage of oncoming trains. This does not preclude the possibility of a separate application for trains to receive warnings about violating vehicles on the intersecting roadway.

OP-RCVW-18. RCVW will not require any equipment that is not approved by the operating railroad to be placed on a train or in the railroad right-of-way that will add liability and/or maintenance burdens to the rail industry.

Operational Constraints

OC-RCVW-01. Moved to common section. DELETED.

OC-RCVW-02. Moved to common section. DELETED.

OC-RCVW-03. Moved to common section. DELETED.

OC-RCVW-04. The RCVW application will be limited by the amount of data available. Customization for individual driving habits, for example, will not be required for initial deployment. As data becomes available to the application over time, the algorithm might be enhanced to include all available, relevant information.

OC-RCVW-05. Moved to common section. DELETED.

OC-RCVW-06. The driver is only provided assistance in decision-making. Regulatory signs at the railroad crossing control traffic flow; the RCVW application only assists the driver in obeying traffic laws. The interface solutions are targeted toward the driver and it is assumed that the driver is responsible for any crash that would occur. Improving the decision making of drivers will therefore reduce the likelihood that the same type of crash occurs. Alerts and warnings to the train might be provided with a separate safety application about a crash-imminent scenario with vehicles crossing the train's path.

OC-RCVW-07. The application uses only a prohibitive frame. All the interface solutions use a prohibitive framework (e.g., "unsafe to cross"). This is important because a permissive framework has increased liability if compliance leads to a crash.

OC-RCVW-08. DELETED

5.2.4 Proposed Application: Spot Weather Information Warning (SWIW)

Operational Policies

OP-SWIW-01. Moved to common section. DELETED

OP-SWIW-02. Moved to common section. DELETED

OP-SWIW-03. Moved to common section. DELETED.

OP-SWIW-04. Moved to common section. DELETED

OP-SWIW-05. Moved to common section. DELETED

OP-SWIW-06. DELETED

OP-SWIW-07. DELETED..

OP-SWIW-08. The SWIW application will benefit both equipped and non-equipped vehicle.

OP-SWIW-09. DELETED

OP-SWIW-10. Moved to common section. DELETED.

OP-SWIW-11. Moved to common section. DELETED.

OP-SWIW-12. DELETED..

OP-SWIW-13. Inserted as a common user need. DELETED

OP-SWIW-14. DELETED.

OP-SWIW-15. DELETED.

OP-SWIW-16. DELETED.

OP-SWIW-17. (Optional) Recommended speeds shall not exceed static or variable “enforceable” speed limits. Not all locations allow for variable speed limits and agencies may wish to avoid potentially confusing conflicting information with static speed limit signage.

Operational Constraints

OC-SWIW-01. Moved to common section. DELETED.

OC-SWIW-02. Moved to common section. DELETED.

OC-SWIW-03. Moved to common section. DELETED.

OC-SWIW-04. The SWIW application will be limited by the amount of data available. The SWIW application will be limited to the types of weather impacts for which it can recommend advisory messages, alerts, or warnings by the type of sensors and gauges at the RWIS station. Additionally, customization for individual driving habits will not be required for initial deployment.

As data becomes available to the application over time, the algorithm may be enhanced to include all available, relevant information.

OC-SWIW-05. The SWIW application is specific for individual vehicles and does not require the detection of or communication with other vehicles. The SWIW application accounts only for the equipped vehicle. The application does not require accounting for other vehicles on the roadway. SWIW does not require providing warnings of an impending crash with other vehicles. This information may be addressed through other applications.

OC-SWIW-06. Moved to common section. DELETED

5.2.5 Proposed Application: Oversize Vehicle Warning (OVW)

Operational Policies

OP-OVW-01. Moved to common section. DELETED

OP-OVW-02. DII is robust in outdoor roadside conditions. Each interface solution is visible in winter conditions, such as blowing and drifting snow. The interfaces must also withstand plowing and not interfere with plow operations. The application must be visible in direct and indirect sunlight (i.e., minimal interference from glare or shadows) and withstand all temperature, humidity, vibration, and electrical conditions at the roadside.

OP-OVW-03. Messages are visible during the day and at night. The interface solutions are visible both during the day and at night.

OP-OVW-04. The OVW application will benefit both equipped and non-equipped vehicles.

OP-OVW-05. The OVW application evaluates vertical and/or horizontal clearance. Length evaluation may be included when applicable.

OP-OVW-06. Moved to common section. DELETED

OP-OVW-07. Moved to common section. DELETED

OP-OVW-08. Moved to common section. DELETED

OP-OVW-09. Moved to common section. DELETED

OP-OVW-10. Moved to common section. DELETED

OP-OVW-11. Moved to common section. DELETED

OP-OVW-12. Inserted as a common user need. DELETED

OP-OVW-13. DELETED

OP-OVW-14. In the event multiple oversize vehicles are passing a location, the roadside infrastructure will act conservatively when determining whether an alert or warning is necessary. The DII will issue an alert/warning regarding a roadway obstacle (e.g. low height and/or narrow horizontal clearance), when at least one vehicle within the group of passing vehicles is detected, measured, and determined to be too large to safely pass through the obstacle (e.g., bridge or tunnel)

OP-OVW-15. No alert and/or warning is provided to the driver if the vehicle is within roadway obstacle clearance limits. (e.g., alerts and/or warnings are only issued if the vehicle measurements exceed the bridge or tunnel's clearance levels.)

OP-OVW-16. Roadside infrastructure is used to measure the oversize vehicle dimensions, location coordinates, and timestamp

OP-OVW-17. Vehicle measurements should not be stored on the vehicle application beyond the applicable zone. Due to the potential for vehicle measurements to change (e.g., a CMV swapping cargo) vehicle measurements are only stored by the application for a finite period of time

OP-OVW-18. The OVW application shall not be prescriptive. The application only provides the driver with information regarding clearance. It is the responsibility of the driver to determine how to utilize this information to avoid a roadway obstacle collision

OP-OVW-19. The OVW application may provide a single or two-stage alert/warning. It provides an alert prior to a critical decision point for an alternate route and/or a warning of imminent danger prior to the point of roadway obstacle collision.

OP-OVW-20. DELETED

OP-OVW-21. The accuracy of the roadway obstacle dimension and position information provided by the roadside infrastructure shall be maintained.

Operational Constraints

OC-OVW-01. Moved to common section. DELETED

OC-OVW-02. Moved to common section. DELETED

OC-OVW-03. Moved to common section. DELETED

OC-OVW-04. The OVW application is single-vehicle based and does not require the communication of other vehicles. OVW does not require providing warnings of an impending crash with other vehicles. This information may be addressed through other applications.

OC-OVW-05. Moved to common section. DELETED

OC-OVW-06. The application uses only a prohibitive frame. All the interface solutions use a prohibitive framework (e.g., "oversize, take alternate route"). This is important because a permissive framework has increased liability if compliance leads to a crash (see Donath and Shankwitz, 2001).

5.2.6 Proposed Application: Reduced Speed Zone Warning (RSZW)

Operational Policies

OP-RSZW-01. DELETED

OP-RSZW-02. Moved to common section. DELETED

OP-RSZW-03. DELETED

OP-RSZW-04. DELETED

OP-RSZW-05. The RSZW application will benefit both equipped and non-equipped vehicle.

OP-RSZW-06. Moved to common section. DELETED

OP-RSZW-07. Moved to common section. DELETED

OP-RSZW-08. Moved to common section. DELETED

OP-RSZW-09. Moved to common section. DELETED

OP-RSZW-10. Moved to common section. DELETED

OP-RSZW-11. Moved to common section. DELETED

OP-RSZW-12. Moved to common section. DELETED

OP-RSZW-13. DELETED

OP-RSZW-14. In the event multiple vehicles are passing a location, the roadside infrastructure will act when the minimal conditions are triggered that would warrant an alert or warning. The DII will issue an alert/warning regarding the need to reduce speed, when at least one vehicle within the group of passing vehicles is detected, measured, and determined to be driving at a speed higher than the posted speed limit of the reduced speed zone.

OP-RSZW-15. No speed-related alert and/or warning is provided to the driver if the vehicle is driving at or below the reduced speed zone posted speed limit. Alerts/warnings are only issued if the vehicle speed is measured to be above the posted reduced speed zone speed limit.

OP-RSZW-16. Changed roadway configuration notification is always provided to the driver. Notification regarding changes to the roadway configuration is always provided to the driver regardless of the driver's current speed.

OP-RSZW-17. Infrastructure data equipment is used to measure the vehicle's speed for the infrastructure application.

OP-RSZW-18. DELETED

OP-RSZW-19. Reduced speed alert/warning is determined by the infrastructure and the vehicle. The infrastructure transmits roadside data to the vehicles traveling into the reduced speed zone. The infrastructure uses the measured real-time speed of the passing vehicle and provides an alert/warning to the driver from the DII, as necessary. The vehicle also determines the necessary alert/warning to provide to the driver thru the DVI.

OP-RSZW-20. The RSZW application shall not be prescriptive. The application only provides the driver, by default, roadway configuration information regardless of vehicle speed (at, below, or above the posted speed limit). The application only provides the driver speed information when the vehicle is above the posted speed limit. It is the responsibility of the driver to determine how to utilize this information, at all times, to avoid a crash.

OP-RSZW-21. DELETED

Operational Constraints

OC-RSZW-01. Moved to common section. DELETED

OC-RSZW-02. Moved to common section. DELETED

OC-RSZW-03. Moved to common section. DELETED

OC-RSZW-04. The RSZW application is single-vehicle based and does not require the communication of other vehicles. RSZW does not require providing warnings of an impending crash with other vehicles. This information may be addressed through other applications.

OC-RSZW-05. Moved to common section. DELETED

OC-RSZW-06. The application uses only a prohibitive frame. All the interface solutions use a prohibitive framework (e.g., “slow down, lane change ahead”). This is important because a permissive framework has increased liability if compliance leads to a crash (see Donath and Shankwitz, 2001).

5.3 Descriptions of the Proposed System

This section describes each proposed safety application including major components and interfaces as well as the capabilities and functions of the system. The general framework for the connected vehicle V2I safety applications is shown in Figure 5-1.[54] It includes both the vehicle and infrastructure platforms that house the applications. Regarding communications components, the intention for this ConOps is that the vehicle and roadside communication links shall be compliant with the emerging DOT enabling foundation and the specifics of its performance requirements will vary by application and be defined in that phase of the application. The intended SOI is a platform that will support one or more safety applications. Inclusion of infrastructure data equipment and infrastructure signage in the SOI is dependent upon the specific application as well as the presence of existing signage. The USDOT connected vehicle core system contains additional components for security and other purposes that are not presented in this diagram. More specific diagrams of individual safety applications are presented in the subsections below.

[54] The figures in this section are repeated from those presented in the summary in Section 1, for convenience.

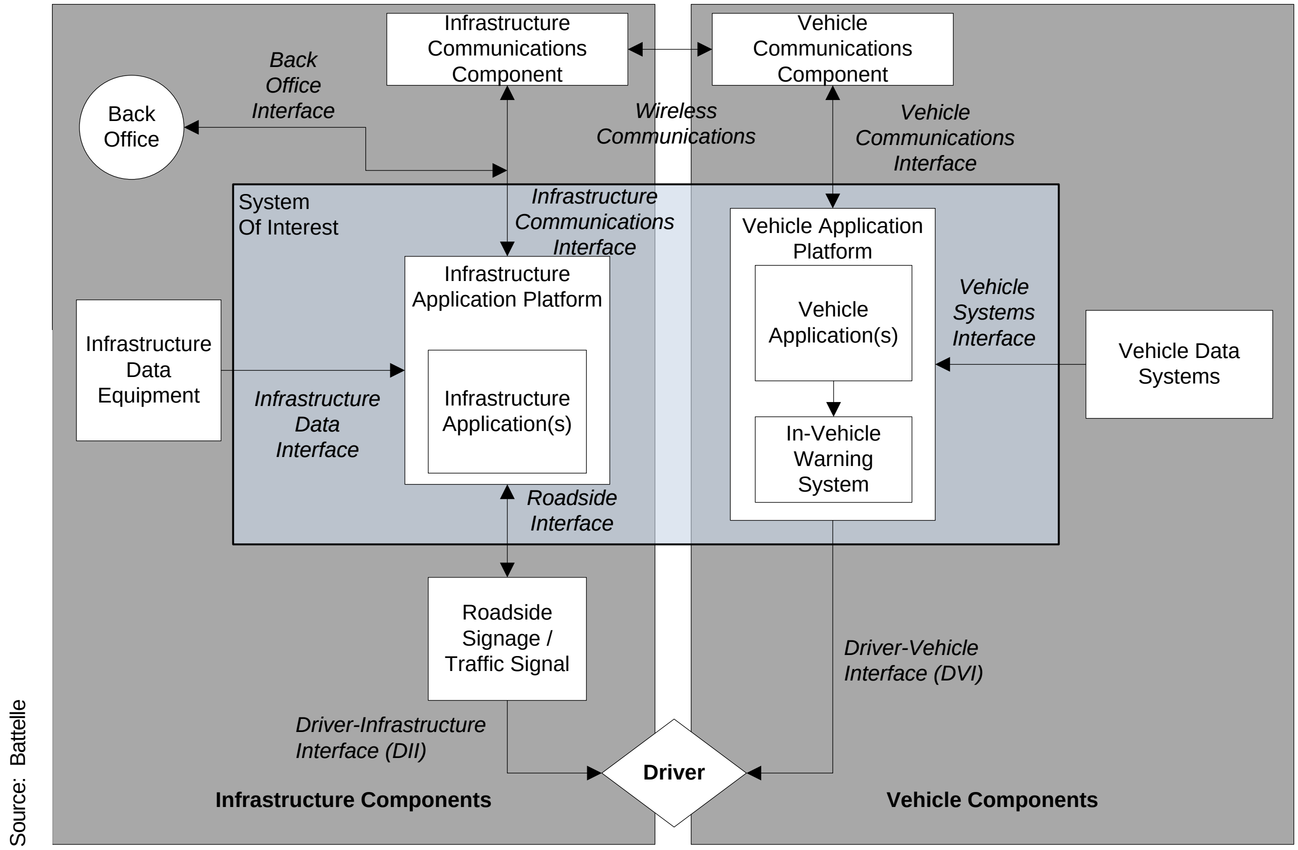


Figure 5-1. General Framework for Connected Vehicle V2I Safety Applications

As shown in Figure 5-1, many components make up the SOI:

- SOI Components
  - Infrastructure Application Platform
  - Infrastructure Application(s)
  - Vehicle Application Platform
  - Vehicle Application(s)
  - Onboard Warning System
- Supporting Components
  - Infrastructure Communications Component
  - Vehicle Communications Component
  - Back Office
  - Infrastructure Data Equipment
  - Roadside Signage/Traffic Signal
  - Vehicle Data Systems.

The following paragraphs describe each component listed above.

Infrastructure Application Platform

The Infrastructure Application Platform will communicate with the Infrastructure Communications Component, accept information from the Infrastructure Data Equipment, host the infrastructure-based safety application(s), and communicate with the Roadside Signage/Traffic Signal.

Infrastructure Application(s)

The Infrastructure Application(s) is the infrastructure component of the safety applications. This contains the infrastructure-based algorithm for one or more safety applications.

Vehicle Application Platform

The Vehicle Application Platform will communicate with the Vehicle Communications Component, accept information from the Vehicle Data Systems, host the vehicle-based safety application, and communicate with the Onboard Warning System.

Vehicle Application(s)

The Vehicle Application is the vehicle component of the safety applications. This contains the vehicle-based algorithm for one or more safety applications.

Onboard Warning System

The Onboard Warning System is a device that will provide an indication of a safety application warning to the driver. Typically, the indication will be aural and/or visual; however, alternate indications such as haptic warnings may be provided. When multiple safety applications are hosted on the Vehicle Applications Platform, the Onboard Warning System will prioritize alerts and warnings from the multiple safety applications.

Infrastructure Communications Component

The Infrastructure Communications Component is a wireless communications device that enables the Infrastructure Application Platform a means to communicate with a Connected Vehicle's Vehicle Communications Component.

Vehicle Communications Component

The Vehicle Communications Component is a wireless communications device that enables the Vehicle Application Platform a means to communicate with an equipped Infrastructure Communications Component.

Back Office

The Back Office represents a system that is located remote to the Infrastructure and is used by the operator of the Infrastructure Components. The Back Office may be an optional system due to cost constraints of the maintainer of the infrastructure. However, the Back Office system could be used to help facilitate the collection of diagnostic data from the Infrastructure Application. The Back Office may also provide a means to supply dynamic (current) data to the Infrastructure Application or possibly a remote mechanism for updates to the Infrastructure Application.

Infrastructure Data Equipment

Infrastructure Data Equipment represents equipment that provides infrastructure information to the Infrastructure Application. Some examples may include: Weather Information, Surface Conditions, Visibility, and Vehicle Detection.

Roadside Signage

An integral part of the infrastructure interface with the driver is Roadside Signage. Roadside Signage provides alerting capabilities for both equipped and non-equipped connected vehicles.

Vehicle Data Systems

The Vehicle Data Systems represent systems within the vehicle that provide vehicle related data to the Vehicle Application. Data provided may come from a positioning system, vehicle data bus, sensors, actuators on the vehicle, or stability systems. Specific interfaces to vehicle systems will be dependent on specific information required to support the safety application.

5.3.1 Proposed Application: Stop Sign Violation Warning (SSVW)

The SSVW application framework is depicted in Figure 5-2, and mirrors the general framework diagram above. Note that infrastructure components are not necessarily required at the stop-controlled intersection of interest because the nature of this scenario does not require dynamic, real-time information related to the intersection state itself (it has a stop sign) to be available. As such, the required information might be transmitted to passing vehicles from an RSE placed in other locations that enable V2I safety applications for the specific of interest.

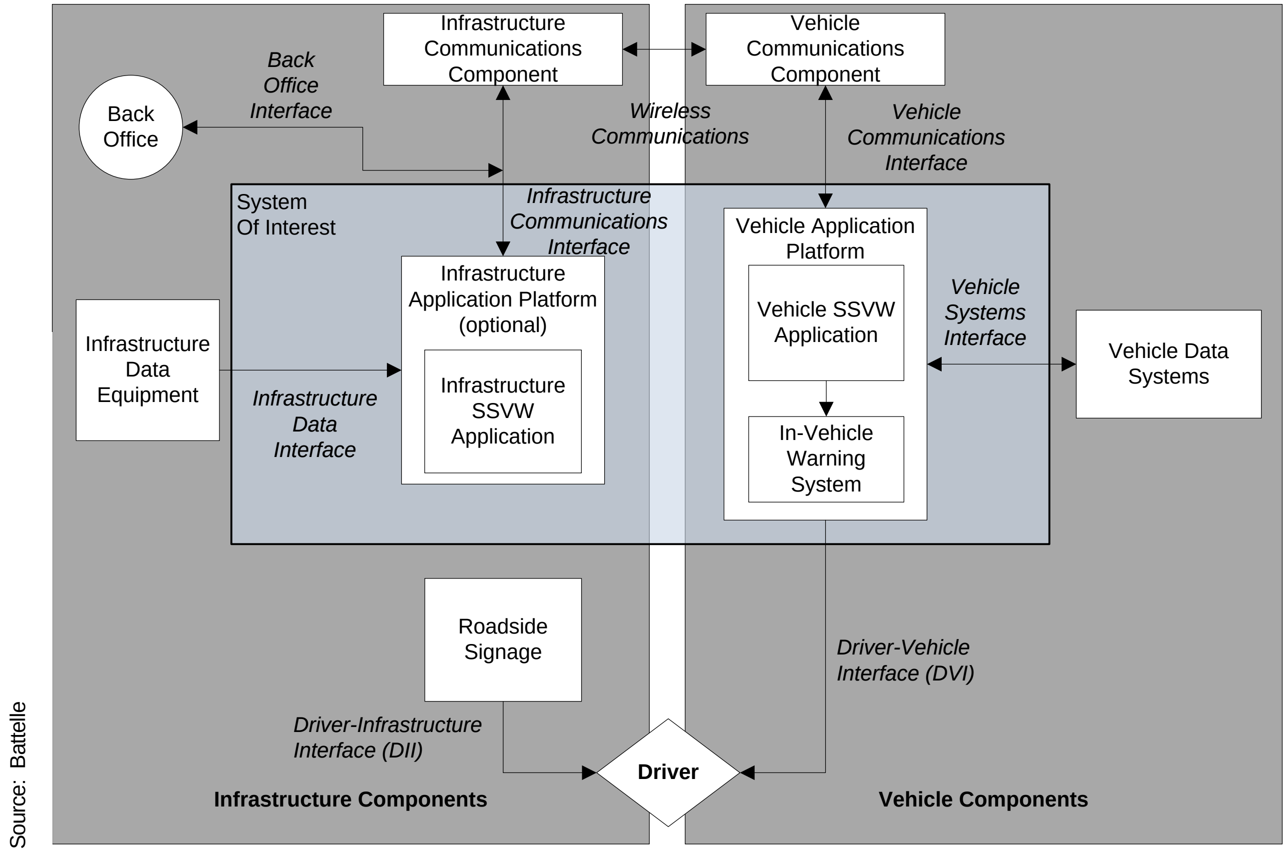


Figure 5-2. Stop Sign Violation Warning Application Diagram

SSVW capabilities are dependent on the cooperation of infrastructure and vehicle components to achieve the application's operational objectives. The paragraphs below discuss what capabilities are present when SSVW equipment is deployed at an stop-controlled intersection or enabled via other roadside equipment in the area. For each SSVW stop-controlled intersection, the infrastructure SSVW application broadcasts messages that include, but are not limited to, the following:

1. Intersection geometry information messages
2. A positioning correction message (Optional)
3. Road surface information and other weather-related data if available (Optional)
4. An SSVW application service announcement (i.e., an announcement that the intersection has information for the vehicle) (Optional).

The content of these messages has not been finalized. The following briefly describes the contents of each of these messages. The final message sets may include additional or different information:

1. *Intersection Geometry Information Messages:* This message contains the intersection information including intersection identification (ID), road/lane geometry for all approach roads (e.g., geometric intersection design, or GID), location of stop lines, and lane numbering scheme associated with movements.
    a. The vehicle interrogates a version number associated with the messages available at the intersection to determine if it needs to download a new version of the information; it only does so if the version number indicates that the new information is more up-to-date than the one currently stored in the vehicle's data store. The vehicle uses the intersection ID to match itself to the correct intersection. The vehicle needs the road/lane geometry to match itself to the approach road and the specific lane[55] on the approach road, if such accuracy is needed. The vehicle uses the location of the intersection stop lines, which could be different for different lanes, to determine the distance from the stopping location. This distance is an important parameter for the warning calculation.
    b. SSVW equipment is optional at the intersection, and it is possible for required information to be transmitted from other RSE in the area (e.g., RSE used for other V2I safety applications at other intersections). The option for use of off-site RSE adds the need for the vehicle to verify that the required information is reasonably current, as well as the possibility that not all equipped vehicles will have the information required to activate the SSVW application.
2. *Positioning Correction Message (Optional):* This message contains the GPS positioning correction information for the intersection that the vehicle may use to improve its estimate of location within the intersection.
3. *Road Surface Information and Other Weather-Related Data (Optional):* SSVW equipment might transmit information to the vehicle about the road surface coefficient of friction at the intersection, and weather related data such as dew point, temperature, visibility, rain, etc. that may assist the onboard SSVW application in adjusting warning timing to account for variations in stopping distance.
4. *Service Announcement (Optional):* The service announcement provides vehicles with the intersection's identification (ID) code number and indicates whether the intersection's SSVW capability is operational. It also states whether intersection geometry information is available, the version number of the currently available intersection geometry information, and the channel on which the information is broadcast. This announcement is optional, because the application instead could simply continuously broadcast intersection geometry information messages that would inherently indicate the SSVW capabilities of the intersection and availability of information.

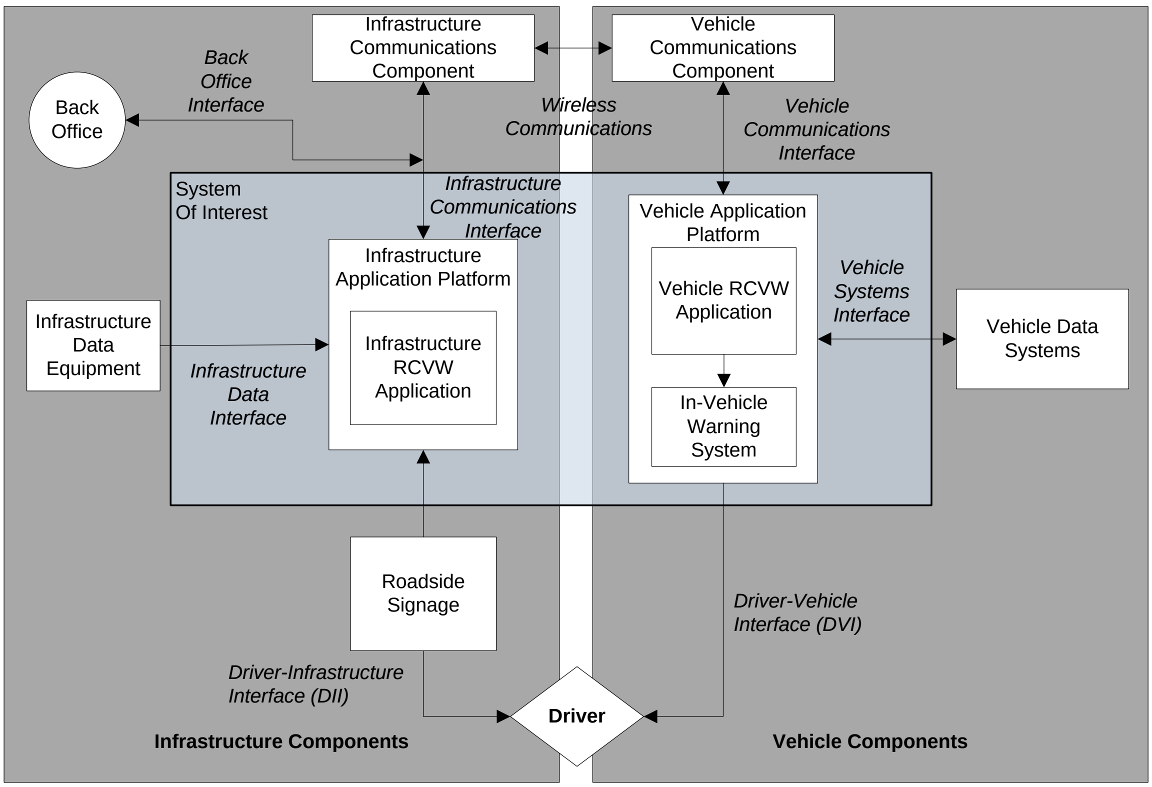
When an SSVW equipped vehicle approaches an SSVW equipped intersection, the actions that the vehicle performs depend on whether the intersection has SSVW infrastructure components, or whether the required information has already been transmitted to and archived by the vehicle. Assuming the required information is available, either on the vehicle or from RSE at the

[55] Examples of different lane types that need to be identified are: dedicated left/right turn lanes and bicycle lanes that can be used as turn lanes. Other types exist.

intersection, the onboard SSVW application processes all available data regarding both the vehicle and intersection, providing the driver a warning about a potential stop sign violation.

5.3.2 Proposed Application: Railroad Crossing Violation Warning (RCVW)

Figure 5-3 presents an overview of the RCVW application, and mirrors the general framework diagram presented in Figure 5-1. The overview is illustrated in terms of both infrastructure and vehicle components. Note that data from the railroad and/or train is an optional component depending upon arrangements with the railroad.



Source: Battelle

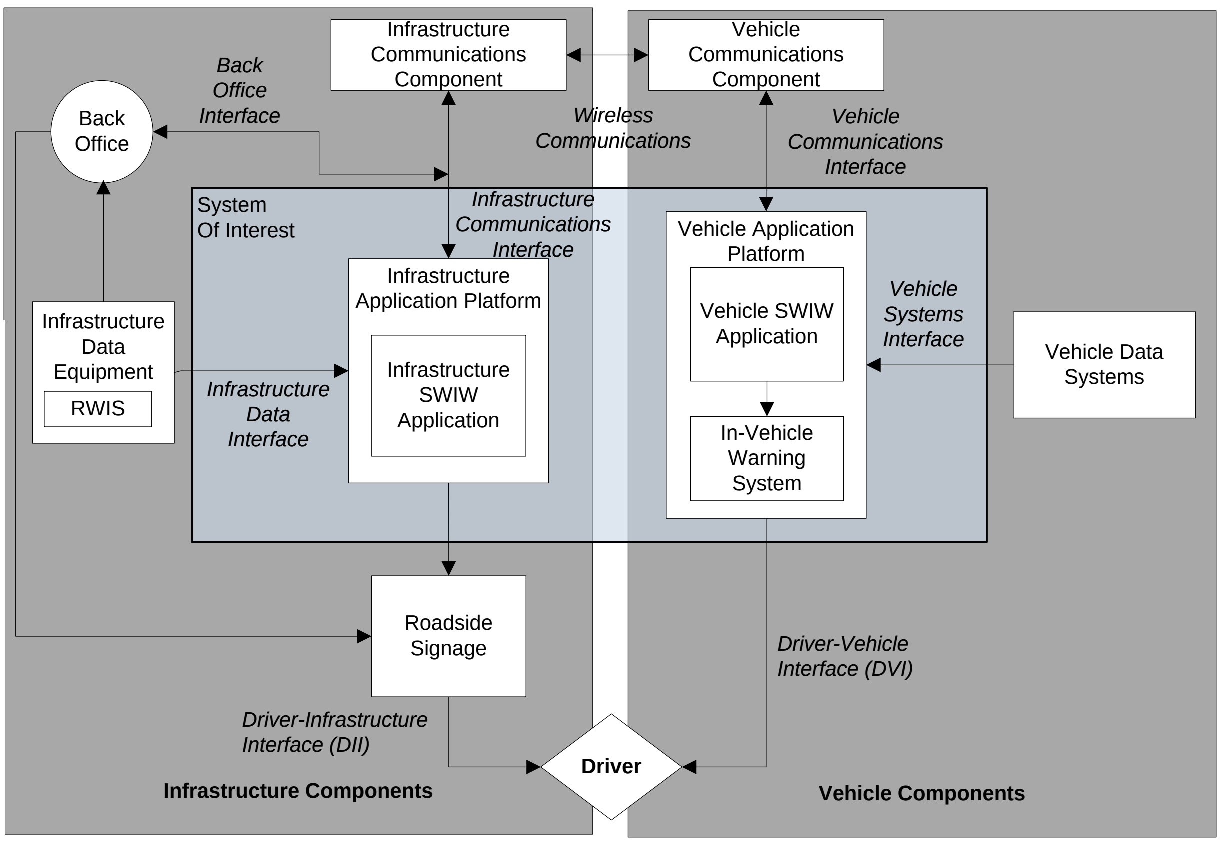
Figure 5-3. Railroad Crossing Violation Warning Application Diagram

Detecting train presence through the infrastructure data equipment in the public right-of-way may be necessary, depending on the availability of information from an interconnect interface between a signal warning system and track circuits on the railroad. This component might consist of any detection product (i.e., radar, lidar, cameras, or, depending on technologies utilized by the railroad industry, positive train control (PTC) reader or RFID reader) that detect initial train presence. This information is essential to determine when the application should transmit an alert or warning. Depending on the deployed technology, the system might also be capable of detecting train presence for the full-length of the train and/or provide additional data such as train speed.

The train detection system or transmitted data from the railroad or train is necessary for determining the present status of the intersection in terms of gaps in cross-traffic. Either data from the railroad signal warning system, specifically through the interconnect interface between a signal warning system and track circuits on the railroad, or train detection system sensors in the public right of way would detect the presence, distance, and speed of any train within a coverage zone for the crossing, and from that the roadside application computes when conditions are unsafe for a driver to proceed across the at-grade rail crossing. When unsafe conditions are detected, the driver is warned via the DVI. Positioning correction information may be desired for some circumstances, such as when there is an intersecting roadway parallel to the railroad that may contain a turn lane for vehicles to turn onto the roadway toward the at-grade railroad crossing.

5.3.3 Proposed Application: Spot Weather Impact Warning (SWIW)

Figure 5-4 presents an overview of the SWIW application, and mirrors the general framework diagram presented in Figure 5-1. The overview is illustrated in terms of both infrastructure and vehicle components.



Source: Battelle

Figure 5-4. Spot Weather Impact Warning Application Diagram

The limiting factor in the capabilities of the SWIW application is the availability and coverage of ESS data. The application utilizes available RWIS data from ESS specific to the issue(s) being addressed at a given site. Sensors could detect low visibility due to fog or smoke; surface conditions, such as wet or icy pavement; flooding; and high winds that would affect traffic, particularly commercial vehicles. Data required by the infrastructure application for the determination of advisory messages, alerts, or warnings would necessarily vary for each of these weather impacts. At a minimum, visibility sensors would be required to detect low visibility; various instruments to monitor surface conditions might include a rain gauge, thermometer, and pavement sensors; flood gauges to monitor stream levels for flooding concerns; and anemometers to monitor for high wind speeds. Other relevant traffic data might include detection of vehicle speeds to be used for suggestions of reduced advisory or enforceable speeds, and/or validation of weather impacts to current traffic conditions. Due to potential reliability concerns with RWIS and the need for minimal false alarms, the availability of a back office TMC and/or traffic data for validation purposes is essential to determine when the application should transmit an advisory message, alert, or warning. Data available from equipped vehicles to be used by the application may include temperature and vehicle telematics data (e.g., speed, windshield wiper status, application of traction control). When unsafe conditions are detected and validated, an advisory message, alert, or warning is provided to the driver via available DII and/or DVI. Depending upon the nature of the weather impact, the message may include recommendation for reduced speed or diversion via an alternate route.

5.3.4 Proposed Application: Oversize Vehicle Warning (OVW)

Figure 5-3 presents an overview of the OVW application, and mirrors the general framework diagram presented in Figure 5-1. The overview is illustrated in terms of both infrastructure and vehicle components.

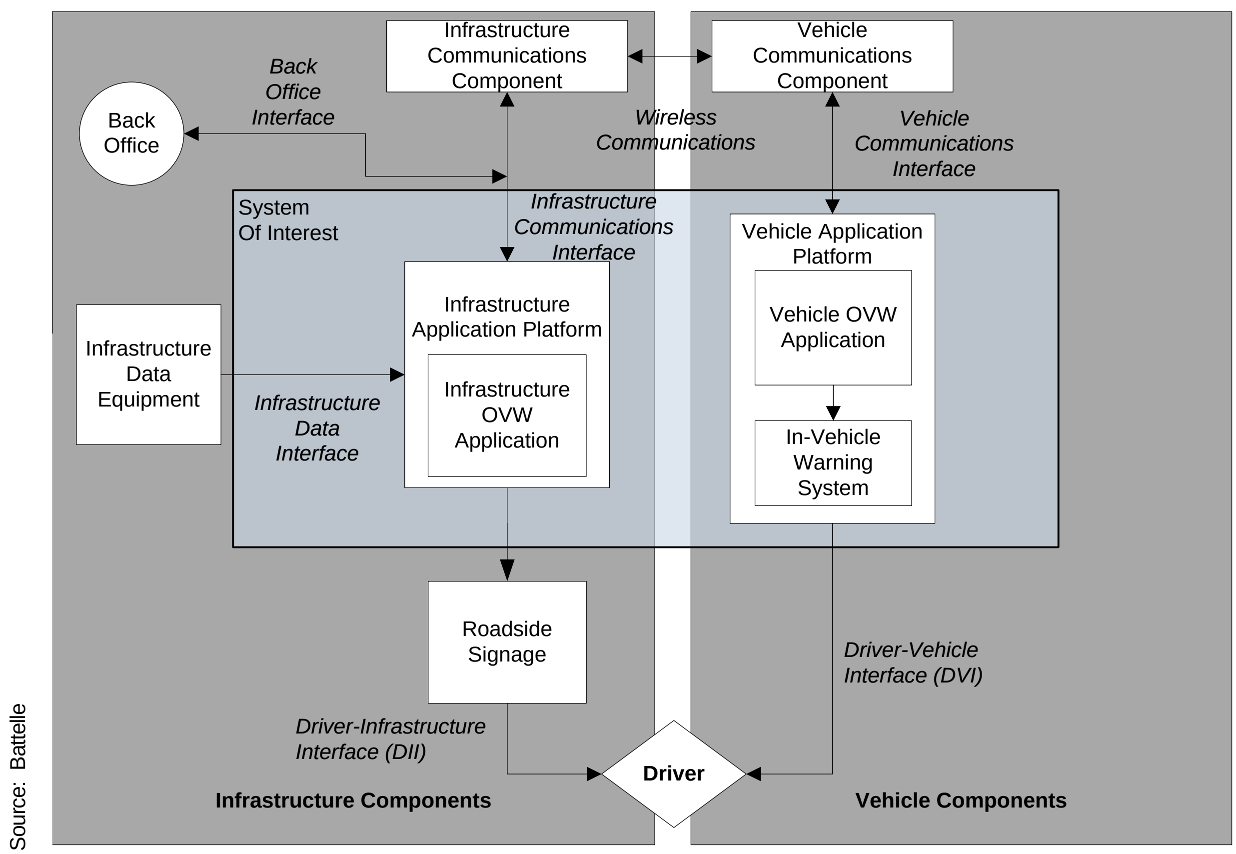


Figure 5-5. Oversize Vehicle Application Diagram

The OVW application uses external measurements taken by the roadside infrastructure, and transmitted to the vehicle, to determine clearance levels and whether an alert/warning is necessary. Specifically, the infrastructure data equipment detects and measures the approaching vehicle's length and width. The infrastructure component of the application transmits the vehicle measurements, along with roadway clearance obstacle geometry, to the OVW vehicle application. The vehicle application utilizes these data to determine whether the vehicle can clear the roadway clearance obstacle. If deemed necessary, the driver is alerted to the impending roadway clearance obstacle prior to a decision point, enabling the vehicle to reroute and avoid a collision. If the vehicle ignores the alert and continues along the route, it will receive a warning indicating an impending collision at a point near the roadway clearance obstacle approach.

5.3.5 Proposed Application: Reduced Speed Zone Warning

Figure 5-3 presents an overview of the RSZW application, and mirrors the general framework diagram presented in Figure 5-1. The overview is illustrated in terms of both infrastructure and vehicle components.

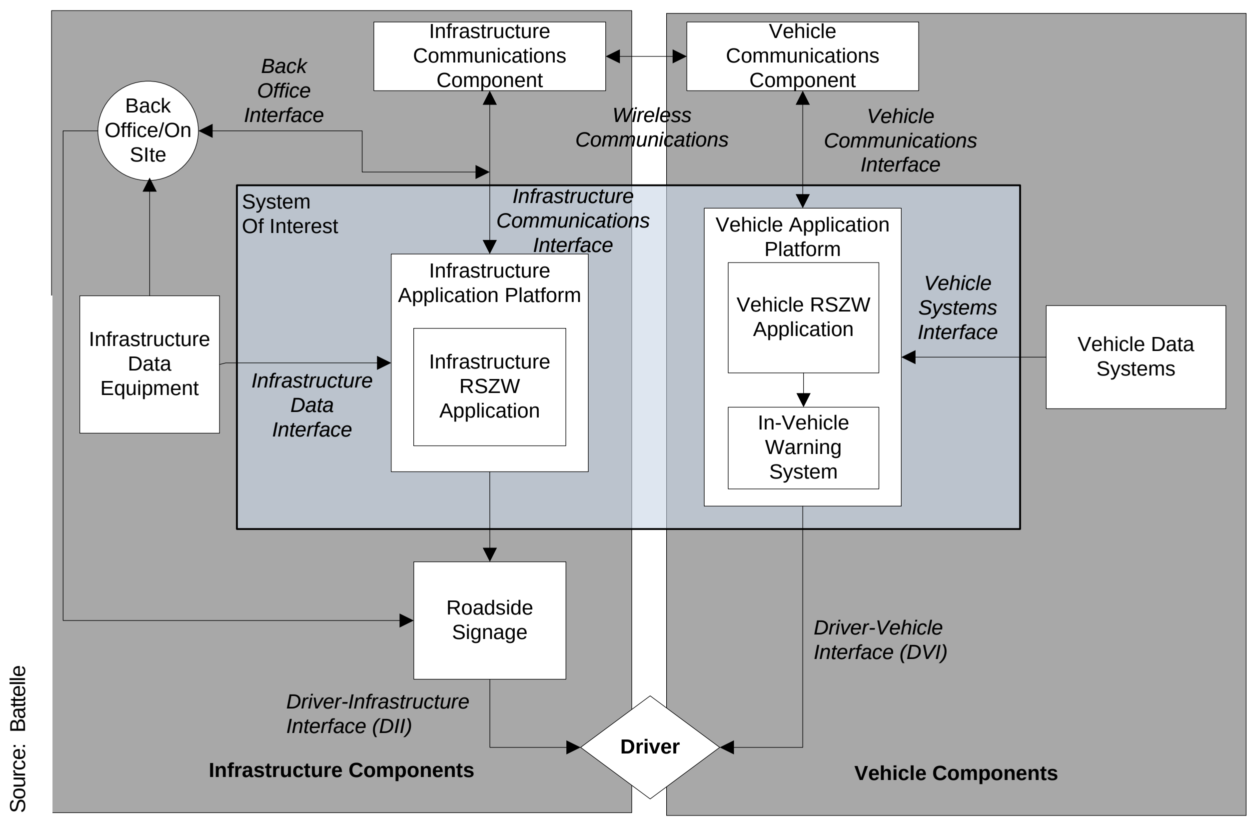


Figure 5-6. Reduced Speed Zone Warning Application Diagram

The RSZW application uses speed measurements taken by the roadside infrastructure along with any applicable changed roadside configuration information provided by the back office and transmits it to the vehicle, to determine whether an alert/warning is necessary. Specifically, the infrastructure data equipment detects and measures the speed of the approaching vehicle and sends this information along with the reduced speed zone posted speed limit, roadway configuration and geometry and current DII signage (to ensure there is no conflict between the DII and DVI) to the approaching vehicle. The vehicle application utilizes this data, along with its own system data (vehicle speed and vehicle position), to determine whether the vehicle needs to slow down. If deemed necessary, the driver is alerted and/or warned. Regardless of the need for a speed-related warning, roadside configuration information is presented to the driver whenever configuration changes occur. Additionally, for situations requiring a merge, a warning might be provided to drivers that have not yet merged and are in danger of a collision given current speed and distance to the merge point.

5.4 Modes of Operation

This subsection describes the various modes of operation for the proposed applications.

5.4.1 Normal Operation

Stop Sign Violation Warning

For normal operations of the SSVW application, the state of the driver is unknown. The driver may be attentive, inattentive, distracted, incapacitated, or impaired. The driver may have the intent to obey or violate the traffic control he or she is approaching. Normal operation includes the assumption that the vehicle will have to stop regardless of any variation on intersection types:

- *Simple Stop-Controlled Intersection Approach.* The SSVW enabled vehicle is approaching an SSVW enabled intersection with or without dedicated turn lanes, which may have only static roadside signage or additional flashing traffic beacons. Regardless of intersection type, the vehicle on the minor road is required to stop.
- *Reduced Visibility.* There are two types of reduced visibility scenarios that SSVW may consider, depending on the availability of local weather information. The first is when the reduced visibility is caused by weather, such as rain, snow, fog, or time of day (for darkness or sun glare). The second is when the reduced visibility is caused by obstructions in the driver's line of sight to the roadside signage, e.g., vegetation, or a temporary object (such as a large parked or moving truck that blocks a driver's line of sight). In both cases, the presence of SSVW in the vehicle and at the intersection enables the driver to be alerted about the presence of the traffic control and alerted to the potential for a violation.

Railroad Crossing Violation Warning

Application is working with normal capability such that information is presented on the DVI, when applicable. The RCVW infrastructure application collects real-time information either via a train detection system in the public right of way or via the interconnect interface leading to a signal warning system controller from the track circuits on the railroad. This information is collected by the infrastructure and communicated to all equipped vehicles for the vehicle to process. Appropriate alerts or warnings are given, possibly involving additional icons indicating an approaching or crossing train. Only drivers at risk for a crash-imminent scenario are affected by the RCVW application. These displays would indicate to a driver that the application is active, and when the application predicts conditions are unsafe to cross an at-grade rail crossing.

Spot Weather Impact Warning

Application is working with normal capability such that information is presented on the DII and DVI, when applicable. The SWIW infrastructure application collects real-time information via RWIS, as well as other available, relevant infrastructure or vehicle-based data sources. This information is gathered by the infrastructure and communicated to all equipped vehicles. The infrastructure processes the information to determine appropriate alerts or warnings, when necessary. Validation of current weather impacts may occur via the back office TMC or with supplemental infrastructure or vehicle data, such as traffic speed, before any alert or warning is generated. Following validation, the appropriate alert or warning will be communicated to the DII and equipped vehicle when warranted by current weather impacts. The vehicle will process all available information and, if applicable, generate a consistent alert or warning for the driver on the DVI. Specifically, alerts and/or warnings may indicate the need for a driver to reduce speed or consider an alternate route, when applicable, due to adverse weather conditions such as reduced visibility, adverse surface conditions, flooding, or high winds.

Oversize Vehicle Warning

The application is working with normal capacity such that information is presented on the DII and DVI, when applicable. The OVW infrastructure application detects and measures real-time information (i.e., vehicle height and width). This information is collected by the infrastructure and communicated to both the infrastructure and vehicle applications (when a vehicle is equipped). Appropriate alerts and/or warnings are given indicating an impending collision due to a lack of clearance. Only drivers at risk for a crash-imminent scenario are affected by the OVW application. The DII and DVI displays indicate to a driver that the application is active, and when the application predicts that conditions are unsafe at an approaching roadway clearance obstacle.

Reduced Speed Zone Warning

The application is working with normal capacity such that information is presented on the DII and DVI, when applicable. The RSZW infrastructure application detects and measures real-time speed information and receives real-time updates regarding roadway configuration from the back office, which may be either in the field (e.g., for a work zone) or a TMC, for example. This information is collected by the infrastructure and communicated to both the infrastructure and vehicle applications (when a vehicle is equipped). Appropriate alerts and/or warnings are given indicating the need to reduce speed. Only drivers at risk for a crash-imminent scenario are affected by the RSZW application. The DII and DVI displays indicate to a driver that the application is active, and when the application predicts that conditions are unsafe at an approaching reduced speed zone. Additionally, for situations requiring a merge, a warning might be provided to drivers that have not yet merged and are in danger of a collision given current speed and distance to the merge point.

5.4.2 Failure, Diagnostic, and Maintenance Modes

If a failure renders the system ineffective or inaccurate at presenting proper alerts and warnings to the driver, the system will enter a failure mode. Failures can come from any of the V2I safety application components, including communication failures, positioning errors, or data errors. Any DII and DVI sign shall be designed to indicate that it is broken, such that a driver will be aware if the system is inactive. Should a failure that limits DII effectiveness be detected by the system controller, the DII sign will enter a “do no harm,” fail-safe mode in which the intersection or roadway is restored to a state of only static signage. With DII signage in this fail-safe mode, drivers would be able to discern that the signage was inoperable, as opposed to a “safe” situation; the driver is expected to utilize existing roadside signage to make an informed decision on a safe vehicle speed. A blank sign could be used to indicate that the application was inactive. In the event of degraded status of the DVI, a warning light might indicate to the driver that the system was inactive or in need of repair.

Should the infrastructure application be connected to a TMC, the center will be notified of a system failure. If no connection is available, local law enforcement passing through the intersection can manually contact the transportation agency of a noticeable system failure, so that a repair crew can be dispatched.

As with any system, occasional failures occur, and to rectify the situation, a diagnostic session is likely needed to trace and correct the problem. As the system operates, self-diagnostics run periodically. Should a failure be detected, the system will enter a failure mode, which, depending on the severity of the failure, may still allow full or partial operation of the system on one or both minor road intersection approaches.

For maintenance purposes, to the extent possible, V2I safety applications will continue to operate under normal operations. As necessary, a mode of operation may be invoked where the application at the intersection or roadway automatically switches in and out of diagnostic mode for testing purposes. This maintenance mode also includes any scheduled or ad hoc maintenance or repairs to the connected vehicle system used for the application. In the event that any critical infrastructure or vehicle component is off-line, the application will not activate. Instead, the DVI will report the off-line status to the driver and any DII sign will enter the fail-safe mode. The driver is expected to utilize existing roadside signage to navigate the intersection.

5.5 User Classes and Other Involved Personnel

This subsection describes the user classes involved in each application. As described by the IEEE 1362 standard, a user class is distinguished by the ways in which the users interact with the system. A user is anyone who will interact with the proposed system, including operational users, data entry personnel, system operators, operational support personnel, software maintainers, and trainers.

5.5.1 User Classes

Users of the connected vehicle V2I safety applications include the organizations, agencies, and individuals that are necessary for installing, maintaining, operating, and interacting with functioning connected vehicle applications. The primary users of the applications are:

- Automobile OEMs – responsible for original equipment and for vehicle-related equipment and software actions necessary to establish and maintain the onboard connected vehicle system.
- Aftermarket safety device manufacturers – responsible for add-on equipment to retrofit non-equipped vehicles and for vehicle-related equipment and software actions necessary to establish and maintain the onboard connected vehicle system.
- State and local governments and their DOTs – responsible for installing and maintaining all infrastructure-related components, including the overarching foundation network that will supply the communications that support the V2I safety applications, necessary to establish and maintain connected vehicle applications. In the event of a public-private partnership, state and local governments and their DOTs will be responsible for oversight of installation and maintenance of the infrastructure related components.

- USDOT – responsible for developing high-level guidance to state and local agencies in the deployment and operation of connected vehicle V2I safety applications.
- Railroad Companies – responsible for installing and maintaining infrastructure-related components connected to the railroad, specifically, to sensors, detectors, and signal warning systems that detect the presence of an approaching and/or crossing train and visibly and/or audibly warn highway drivers via dynamic signage on an intersecting roadway.
- Vehicle drivers – responsible for the decisions made when approaching and entering an intersection or curve. Drivers are also responsible for:
    - Familiarization with the vehicle safety features
    - Vehicle maintenance, especially of the onboard application components
    - Assessing the traffic situation when an alert or warning is issued, and making a decision.
- Traffic control equipment manufacturers – responsible for the development and maintenance of infrastructure equipment and software that can interface with connected vehicle applications (and other related safety systems, as they are fielded).
- Organization(s) responsible for connected vehicle V2I safety application guidelines and standards – responsible for rules and procedures necessary for connected vehicle V2I safety applications and components to become operational.
- Transportation planners – interact indirectly with the system as they may review data collected on speeds and vehicle types in combination with crash data. They may also interact with traffic operations personnel to analyze any available data for system benefits or to make decisions regarding additional deployments.

Further detail on each primary user class is presented below. Additionally, there may be other secondary users (stakeholders) of connected vehicle V2I safety applications.

Automobile OEMs

Automobile OEMs may participate in application development as part of existing organizational structures. There are additional roles that they will assume to help ensure that connected vehicle V2I safety applications remain in operation over the long term, such as

- Development of standards and certification procedures
- Training of personnel in connected vehicle V2I safety applications
- Connected vehicle V2I safety application hardware and software installation in new vehicles.

Aftermarket Safety Device Manufacturers

Device manufacturers may participate in application development as part of existing organizational structures. There are additional roles that they will assume to help ensure that connected vehicle V2I safety applications remain in operation over the long term, such as

- Development of standards and certification procedures
- Training of personnel in connected vehicle V2I safety applications
- Connected vehicle V2I safety application hardware and software installation in both new and existing vehicles.

State and Local DOTs

Since state and local DOTs currently have the responsibility for roadway safety, they are viewed as having the primary role for the installation and maintenance of infrastructure-based connected vehicle V2I safety applications equipment at intersections and curves. In the event of a public-private partnership, state and local governments and their DOTs many of these responsibilities will transfer to that entity, although this set of users will still be responsible for oversight of installation and maintenance of the infrastructure related components.

State and local DOTs may incorporate the operation and maintenance of connected vehicle V2I safety applications infrastructure-side applications and equipment into their existing transportation management organizations. Additional roles that they may assume include:

- Planning, identifying, and selecting intersections and curves for specific safety applications.
- In conjunction with other state and local DOTs and traffic control equipment manufacturers, maintenance of test beds for testing enhancements and changes to connected vehicle infrastructure-side software and equipment.
- Development of maintenance plans for connected vehicle V2I safety application infrastructure equipment at intersections and curves.
- Installation of connected vehicle infrastructure equipment at selected intersections and curves.
- Installation and maintenance of connectivity between the connected vehicle infrastructure equipment at intersections and the traffic signal controller.
- Validation and maintenance of safety application operation at equipped intersections and curves.
- Installation of back-end connectivity from roadside equipment to TMCs, if needed or desired.
- Generation, maintenance, and updates of any necessary intersection geometry information. Note that responsibility for this item is to be determined, and the State and local DOTs may choose to delegate this role to another entity.
- Participation in standards development activities.
- Training of personnel in connected vehicle V2I safety applications.
- Implementation and maintenance of connectivity from the communications used to support the connected vehicle environment, to State and local DOT centers.

Additionally, State and local DOTs are assumed to be the local connected vehicle network operating entity, which is tasked with the implementation and management of all aspects of the connected vehicle network that include: the wireless communication between an equipped vehicle and the connected vehicle RSE, communications across the backbone network, connectivity to connected vehicle end users, central processing systems required for network and applications support, and nationwide operation centers. The elements of this additional role that are important to connected vehicle V2I safety applications include:

- Implementation and maintenance of the local connected vehicle backbone network to include transmission equipment, computing systems, and operations centers that may be necessary to sustain the nationwide network
- Establishment and management of standards activities that are related to communications

- Establishment, management, and enforcement of policies related to the use of and access to systems that are part of the network; as well as data transmitted using the connected vehicle network
- Establishment, implementation, and management of a security program that addresses both physical and logical threats to the system
- Certification of software for compliance with the Federal Information Security Management Act (FISMA) and other applicable regulations.

USDOT

The USDOT may participate in application development as part of its existing organizational structures. There are additional roles it may assume to enable the success of a nationwide deployment of connected vehicle V2I safety applications, such as

- Development of guidelines to assist state and local agencies in the installation, operation, and maintenance of connected vehicle V2I safety applications
- Development of training materials and training courses related to connected vehicle V2I safety applications installation, operation, and maintenance
- Development of automated tools that can be used to assist in the design of safety applications at specific intersections and curves, and in the performance monitoring of the safety applications
- Participation in joint working groups and standards activities to continually assess stakeholder needs with respect to the safety applications and connected vehicle technology.

Railroad Companies

A connection with railroad sensing and detecting equipment and signal warning systems may be desired, specifically for the RCVW application, for which this user class is relevant. Railroad companies are responsible for installing and maintaining these infrastructure-related components connected to the railroad that detect the presence of an approaching and/or crossing train and visibly and/or audibly warn drivers via dynamic signage on an intersecting roadway.

Vehicle Drivers

Each vehicle driver will experience the connected vehicle V2I safety applications outputs when approaching connected vehicle controlled intersections and curves and will respond to information and warnings as the driver chooses. These applications may influence driver behavior and encourage safe driving practices.

Traffic Control Equipment Manufacturers

Traffic control equipment manufacturers may enhance and modify their organizations to incorporate connected vehicle V2I safety applications into their product lines. This role includes supporting the long-term deployment and maintenance of connected vehicle V2I safety applications (and other related safety systems). Their roles include:

- Development and production of new traffic control equipment that includes connected vehicle V2I safety applications capabilities
- Retrofitting existing traffic control equipment to accommodate connected vehicle V2I safety applications functionality
- Participation in standards activities
- Development of test and installation procedures for connected vehicle V2I safety application infrastructure-side equipment in conjunction with state and local DOTs
- Training of personnel in connected vehicle V2I safety applications
- Training of state and local DOT personnel in the operation and maintenance of connected vehicle V2I safety application infrastructure-side equipment
- Application software updates for connected vehicle V2I safety applications infrastructure-side equipment.

The roles of manufacturers' trade support and standards organizations are represented below.

Transportation Planners

These users will indirectly interact with the system as they may review aggregated data collected on system performance and crash data. They may also interact with traffic operations personnel to analyze data for system benefits or to make decisions regarding additional deployments.[56]

Organization(s) Responsible for V2I Safety Guidelines and Standards

The organization(s) that will be responsible for connected vehicle V2I safety applications guidelines and standards have not yet been identified. The guidelines and standards organization(s) will define the rules and procedures used to determine that equipped intersections and curves are ready for operational use. At a minimum, when a safety application is ready for operational use at an intersection or curve it means that the connected vehicle infrastructure-side equipment, the interfaces between the safety application and the traffic signal controller assembly, and all other related equipment are performing to specified system-level parameters. The guidelines and standards organization(s) will specify the system-level performance parameters, the guidelines for certification, and the guidelines for any diagnostic procedures. These roles need to be resolved.

5.5.2 Additional User Roles

The connected vehicle V2I safety applications represent a new class of safety system that depends on cooperation between infrastructure systems and onboard systems, linked by communication. By its very nature, it requires changes in the roles of state and local DOTs, traffic control equipment manufacturers, and vehicle manufacturers. Later in the deployment cycle/timeline, aftermarket equipment providers and integrators as well as independent vehicle repair businesses will have to acquire the necessary skills to install, maintain, and repair cooperative safety systems. This ConOps only discusses the necessary changes in the roles for infrastructure operators, traffic control equipment manufacturers, and vehicle manufacturers.

[56] The systems will collect data for maintenance, diagnostics and performance assessment. The systems will not collect data on individual vehicles.

5.5.3 Interaction between Stakeholders

The cooperative aspect of connected vehicle V2I safety applications represents a level of interaction between vehicles and the roadway that is unprecedented. The need for information exchange between individual vehicles and RSE may require the establishment of new working relationships among those responsible for the design, development, operation, and maintenance of vehicle and roadway systems. Some of the more traditional roles will be retained within organizations such as automobile OEMs; federal, state, and local transportation agencies; the traffic signal systems industry; and standards organizations, as well as railroad companies in the case of the RCVW application. Interaction among these stakeholders has to date been facilitated through organizations such as AASHTO, the Institute of Transportation Engineers (ITE), the National Electrical Manufacturers Association (NEMA), SAE International, and the American Association of Motor Vehicle Administrators (AAMVA). In some cases to be identified, new organizations or new joint working groups within existing organizations will need to be established to ensure that the national interests in V2I safety applications are appropriately managed.

5.6 Support Environment

This subsection describes the support concepts and support environment for the proposed applications.

5.6.1 Facilities

The need for new facilities necessary for the operation and management of the connected vehicle V2I safety applications is limited, although some users may choose to construct new facilities.

Existing traffic management and maintenance facilities might need additional equipment and network connectivity to equipped intersections and roadways. These facilities may be used for remote monitoring and diagnostics or gathering and archiving data.

Jurisdictional cooperation may be required to deploy systems where the intersecting roadways fall under different control (e.g., state DOT and county or township owned) because application components may be located in the rights of way of both jurisdictions. Complicated intersection or roadway geometries will add to system complexity in that additional sensors may be needed to provide coverage for vertical and horizontal curves, for example. Local utilities are another facility that must be considered for V2I safety applications as a source of electrical power at the roadside.

5.6.2 Equipment and Software

Following is a list of physical equipment and software associated with V2I safety applications. Each item is presented according to its physical location within the system, which may include the roadside, vehicle, or a transportation facility.

Roadside Detection

- Sensors, as necessary, capable of providing data required by the application [e.g., vehicle size (length, height) sensing system, vehicle presence and positioning sensor, RWIS, etc.]
- Wired or wireless communication equipment to deliver sensor information to the application processor
- Power

Roadside Communications

- Communications equipment

Roadside Application Platform (RSE)

- Rugged computer system to run the software, manage system upgrades and software downloads, and store static roadway information
- Power
- Communication channels from roadside sensors
- Interface to DII, if applicable
- Traffic-grade cabinet
- Antenna
- Power and environmental conditioning, as necessary (lightning suppressants, cooling fans, etc.)

Vehicle Application Platform

- Onboard unit to store information, perform computations, and handle information processing within the vehicle, as necessary
- Power
- Interface to DVI
- Antenna

Roadside and/or Vehicle Application Software

- Secure, real-time operating system to run the application and communication interfaces
- Communication software
- V2I safety application software
- Security/authentication software
- Diagnostics software
- Network communication software
- Scheduling software to manage the sequence of broadcasts

Driver Infrastructure Interface (DII)

- Dynamic, variable message sign or static sign with dynamic elements or lights
- Power
- Communication from application processor

Driver Vehicle Interface (DVI)

- Speaker (for audio), screen(s) (for display) or vibration mechanism (for haptic)
- Power
- Communication from application processor.

5.6.3 Personnel

At present, it is not clear what additional personnel will be needed to operate and maintain V2I safety applications once they are deployed. It is anticipated that additional skill sets and training will be required.

5.6.4 Operations Activities

Operations activities include daily operations, planning and performance measurement, and manufacturing of system components. This section explains each of these activities in relation to the V2I safety application users/stakeholders who participate in or oversee them.

- **Establishing Operations.** State and local DOTs will determine locations where a V2I safety application is an appropriate solution for safety issues. Uniform guidelines for doing so should be developed by USDOT. State and local DOTs must then establish the design layout for a selected site; plans for testing, maintenance, and operations; and appropriate policies (e.g., traffic control at intersections). State and local DOTs must generate, verify, and maintain any relevant static information for the application (e.g., intersection geometry information).
- **Daily Operations.** Traffic operations personnel at state and local DOTs are the primary users who will oversee daily operations of the V2I safety applications. They will monitor and maintain system operation. Monitoring the system may take place via field visits or DOT networks to ensure that the system is operating within specified parameters, to gather data from the system for analysis, or to identify potential maintenance needs. Maintenance may involve replacement of components or interfaces if damage or failures occur. It may also include system upgrades as they become available.
- **Planning and Performance Measurement.** Transportation planners may work with traffic operations personnel at state and local DOTs or their designated contractors to use any available data gathered from the V2I safety applications for broader planning activities. They may also use system data, in combination with crash reports, to measure effectiveness of V2I safety applications at reducing crashes.
- **System Component Manufacturing.** Traffic control and vehicle equipment manufacturers will produce or integrate system equipment such as roadside detection, application platforms, and the DII and DVI. They will interact with traffic operations personnel to establish design standards and specifications for interoperability, reliability, and maintainability; installation

specifications and performance requirements; and, as desired, operate and maintain the V2I safety applications by providing software updates, for example.

5.6.5 Support Necessary to Operate the Deployed Applications

Standardization

In order to be implemented in a consistent fashion by jurisdictions, V2I safety application hardware and software may require certification by one or more certification authorities. V2I safety applications will use message and communication standards from the SAE and IEEE. AASHTO and ITE may also need to be involved to develop standards for the location of RSEs.

Training

State and local DOTs across the United States must be trained in the deployment and maintenance of V2I Safety Application systems. This requires the development of consistent plans for training and continuing education of all levels of personnel.

System Upgrades

After the initial deployment of V2I safety applications, additional functionality may be developed. System upgrades, in both hardware and software, must be deployed in a coordinated fashion on a nationwide scale. This will require procedures for testing and certifying both hardware and software upgrades before they are presented for deployment. It will also require procedures for widespread (nationwide) deployment of software upgrades quickly and consistently.

Institutional Cooperation

Institutional structures for cooperation among the USDOT, the OEMs, and other V2I safety application stakeholders (such as traffic control system equipment manufacturers), as well as railroad companies (in the case of the RCVW application) are needed for the continuing successful operation of the V2I safety applications. New working relationships may need to be established to ensure the following:

- Nationwide V2I safety application compatibility – in order to establish and maintain nationwide compatibility of V2I safety applications, appropriate involvement by public and private sector entities in standards development activities will be required. This will include working within existing standards organizations such as SAE, AASHTO, and NEMA; however, new working groups or committees may need to be created within these organizations that are directly related to V2I safety applications. Implementations of V2I safety applications will need to adhere to the standards established by these activities.
- Development of new V2I safety application requirements – in order to identify, design, and implement future application capabilities, appropriate involvement by public and private sector entities in defining the requirements for expanded application functionality will be required. This will involve representation from the application stakeholders in a “national level” working group to set priorities and schedules for the development, testing, and implementation of future V2I safety application enhancements. Once these new application capabilities are developed, existing standards will need to be revised to accommodate the new functionality.

Geospatial Data Management

As safety applications, effective geospatial data management is critical to the operational success. The deployed system will need to have:

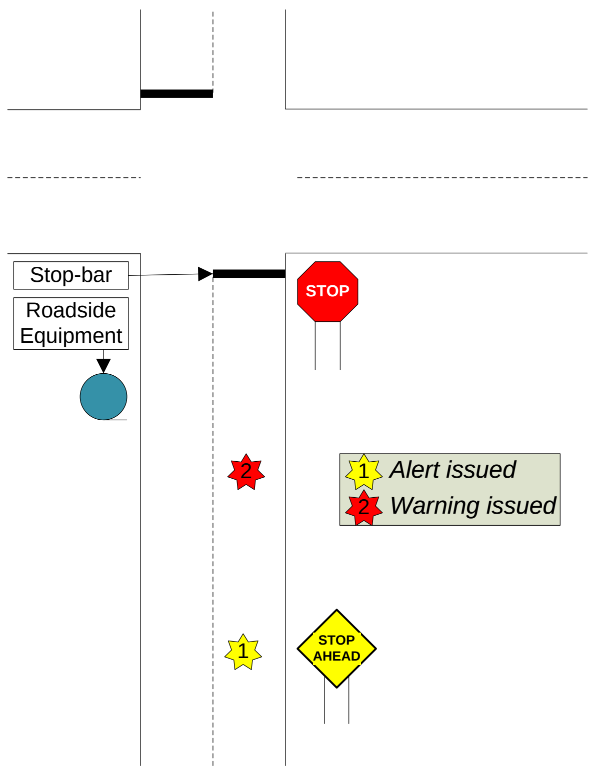
- A geospatial data management system in place to keep track of all planned roadwork at all equipped locations (intersection, curves, ramps, etc.); proactively identify changes to the data sent as part of the application, in particular, installation or removal of signage or other DII; and any changes to the approach geometry or signalization of intersections.
- The capability to disable application functionality at locations where the geospatial information is considered unreliable.

6.0 Operational Scenarios

This chapter will present operational scenarios, which describe how the V2I Safety Applications are envisioned to function. Preconditions and assumptions are given, and then descriptions of how the applications will operate are presented step by step for SSVW, RCVW, SWIW, OVW, and RSZW.

6.1 Stop Sign Violation Warning

The SSVW application is intended to alert and/or warn drivers who are approaching a stop-controlled intersection if they are on a trajectory to violate a stop sign. This application is not intended to advise drivers about proceeding through the intersection. Although the precise timing and algorithm of SSVW-issued alerts and warnings in relation to the intersection approach has not been determined, a general overview of locations of alerts and warnings in relation to the approach of a general intersection is presented in Figure 6-1.



Source: Battelle

Figure 6-1. SSVW Layout

6.1.1 Preconditions and Assumptions

- SSVW-enabled vehicle with an SSVW application platform.
- The vehicle is approaching an SSVW-enabled stop-controlled intersection.
- Information is processed in the vehicle.
- If the vehicle does not receive necessary data, SSVW will be inactive for the intersection.
- If the vehicle positioning information cannot be determined at a road level, the SSVW application will be inactive for the intersection.
- Jurisdictions may have different definitions of legal stops at an intersection, i.e., rolling or complete stops. Further, vehicles commonly advance beyond the stop bar before coming to a complete stop. Thus, appropriate protocols will have to be determined for issuing warnings to vehicles in imminent danger of coming into conflict with cross-traffic, without causing excessive nuisance alarms for vehicles that intend to come to a stop after the stop bar.
- It is expected that the SSVW application will work in conjunction with other safety applications, which may include intersection movement assist or stop sign gap assist (SSGA), or providing information, an alert, or warning to cross-traffic about a violation.
- It is expected that some situations involving law enforcement or emergency vehicles may require these or other SSVW-equipped vehicles to enter an SSVW-equipped intersection without stopping. In this event, it is expected that a "nuisance" warning would be issued by the SSVW application that the driver would understandably and necessarily disregard (as with the stop sign itself, given emergency circumstances).
- Although the normal operating scenarios include a two-stage alert/warning, there may be circumstances in which the distance to the stop bar is too short to distinguish non-compliant and compliant drivers and there is only sufficient time to issue a warning.

6.1.2 Normal Operating Scenario (without roadside equipment)

An equipped vehicle approaches any SSVW-enabled stop-controlled intersection without RSE present at the SSVW intersection. In this scenario, in order for the SSVW application to function, appropriate updated intersection information, presumably from roadside equipment at other locations, must be stored on the vehicle.

Description of Events/Processes

1. An equipped vehicle approaches an SSVW application-enabled intersection.
2. The OBE activates the onboard SSVW application and DVI.
3. The equipped vehicle application processor links current positioning information and (optional) position system correction information to an archived file of SSVW data for the upcoming stop sign controlled intersection:
    - Intersection geometry information (e.g., GID)
    - Special traffic law restrictions for the intersection other than a default complete stop. (e.g., rolling stop, yield only for a right turn, etc.) (only if applicable).

4. The equipped vehicle validates the accuracy of the SSVW information by checking the date of latest authentication, and no record of impending updates
    a. The intersection information is received and authenticated using area geospatial information received elsewhere, e.g., wirelessly, from RSE at other locations like red-light violation warning (RLVW) equipped intersections, etc.
5. The equipped vehicle processes the intersection information:
    a. The SSVW application performs geospatial matching to locate itself relative to the intersection at the road level.
    b. The SSVW application monitors the vehicle speed, and assesses necessary trajectory(s) for the vehicle to prevent a violation from occurring by coming to a stop at the intersection:
        i. The SSVW application makes adjustments in the predicted necessary trajectory for special traffic law restrictions, if applicable.
    c. The SSVW application monitors the vehicle speed for any corrective action (e.g., braking) to determine whether the driver is responding to the stop sign in a way that will prevent a violation from occurring, issuing an appropriate alert and/or warning on the DVI, if warranted:
        i. At an appropriate distance from the stop bar (i.e., at the stop ahead sign, computed as a function of available data using vehicle parameters, roadway geometry, vehicle operating conditions, perception-reaction time, etc.), the SSVW application and DVI may provide an alert to the driver, if deemed necessary by a deceleration algorithm, that a stop sign is ahead.
        ii. At a second, closer distance to the stop bar:
            1. The SSVW application and DVI provide a more urgent warning to the driver, if deemed necessary by a deceleration algorithm that a stop sign is ahead.
            2. Optional: The vehicle will actively prepare for a possible crash in the vehicle: pre-tensioning of safety belts or priming of brake assistance systems, depending on the individual decisions of the vehicle's OEM.
6. After the vehicle has come to a stop at the intersection, the SSVW application terminates operations for the intersection.

6.1.3 Normal Operating Scenario (with roadside equipment)

An equipped vehicle approaches any SSVW-equipped stop-controlled intersection equipped with an RSE capable of providing intersection configuration and geometry data to an equipped vehicle.

Description of Events/Processes

1. An equipped vehicle approaches an SSVW application-enabled intersection and comes in range of the application's roadside communications.
2. The OBE activates the onboard SSVW application and DVI.
3. The equipped vehicle detects available SSVW data:
    - Intersection geometry information (e.g., GID)
    - Area geospatial information (i.e., GID information for multiple intersections in the area) (optional)

- Positioning system corrections (optional)
- RWIS data (optional)
- Special traffic law restrictions for the intersection other than a default complete stop (e.g., rolling stop, yield only for a right turn, etc.) (only if applicable).

4. The equipped vehicle receives and/or updates all static information:
    a. The vehicle decides if it has the current intersection geometry information and traffic law restriction data for the intersection
    b. The vehicle receives and stores any necessary intersection geometry information and traffic law restrictions in its data store, replacing any older information with updates.
5. The equipped vehicle processes the intersection information:
    a. The SSVW application performs geospatial matching using the positioning correction information to locate itself relative to the intersection at the road level.
    b. The SSVW application monitors the vehicle speed, and assesses necessary trajectory(s) (the driver may choose to accelerate or decelerate) for the vehicle to prevent a violation from occurring, i.e., to come to a complete stop at the intersection:
        i. The SSVW application makes adjustments in the predicted necessary trajectory for special traffic law restrictions, if applicable, which may be dependent upon availability of lane level accuracy.
    c. The SSVW application monitors the vehicle speed for any corrective action (e.g., braking) to determine whether the driver is responding to the presence of a stop sign in a way that will prevent a violation from occurring, issuing an appropriate alert and/or warning on the DVI, if warranted:
        i. At an appropriate distance from the stop bar (i.e., at the stop ahead sign, computed as a function of available data using friction factor, vehicle parameters, roadway geometry, vehicle operating conditions, road and weather information, perception-reaction time, etc.), the SSVW application and DVI may provide a visual/haptic/audio alert to the driver, if deemed necessary by a deceleration algorithm, that a stop sign is ahead. Given RWIS data, this will always be generated in low-visibility conditions.
            1. The distance at which an alert or warning is issued will vary depending upon the available data, i.e., vehicle parameters, weather information, etc.
        ii. At a second, closer distance to the stop bar:
            1. The SSVW application and DVI provide a more urgent visual/haptic/audio warning to the driver, if deemed necessary by a deceleration algorithm, that a stop sign is ahead.
            2. Optional: The vehicle will actively prepare for a possible crash in the vehicle: pre-tensioning of safety belts or priming of brake assistance systems, depending on the individual decisions of the vehicle's OEM.
6. After the vehicle has come to a stop at the intersection, the SSVW application terminates operations for the intersection.

6.2 Railroad Crossing Violation Warning

The RCVW application is intended to alert and/or warn drivers who are approaching an at-grade railroad crossing if they are on a crash-imminent trajectory to collide with a crossing or approaching train. Although the precise timing and algorithm of RCVW-issued alerts and warnings in relation to the railroad intersection approach has not been determined, a general overview of locations of alerts and warnings in relation to the approach of a general intersection is presented in Figure 6-2.

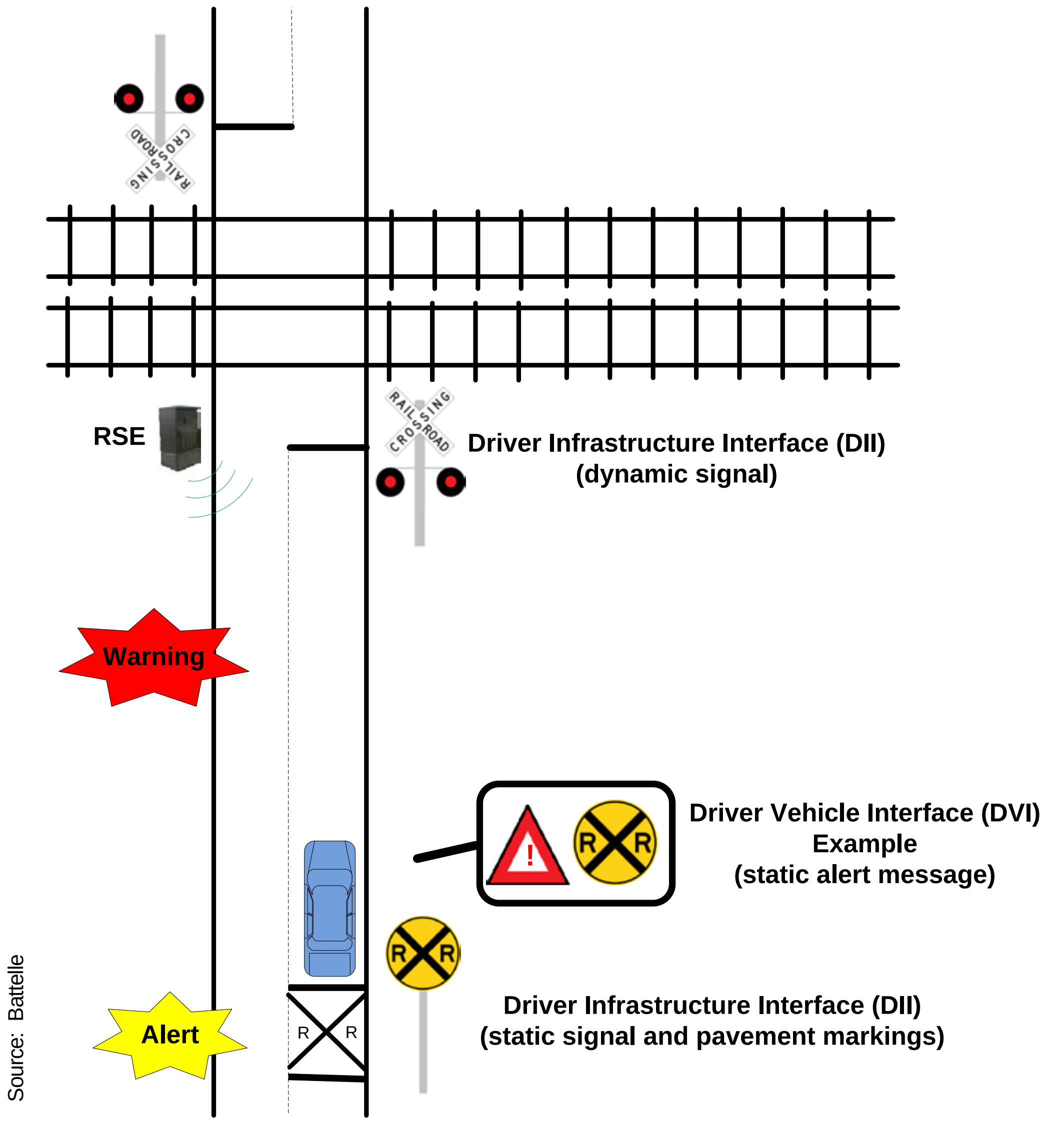


Figure 6-2. RCVW Layout

The RCVW application is intended to provide alerts and warnings drivers approaching a grade-level railroad crossing to facilitate gap selection to proceed through the intersection. The application may vary depending on the intersection geometry, identified needs, and any subsequent research, policies, or constraints of the deploying agency. Two levels of driver notification are envisioned for RCVW, where an “alert” is a cautionary message about an anticipated vehicle conflict and a “warning” is a more urgent message for a more immediate, potentially crash imminent vehicle conflict.

6.2.1 Preconditions and Assumptions

- Application has capabilities to detect presence, speed, distance from the highway-rail crossing, and acceleration of trains.
- The application is intended only for drivers on the intersecting roadway, and will not provide information to or affect the movement of trains.
- In the event of failure of any vital component, e.g., railroad sensors, the RCVW application will not activate, the DVI will remain inactive, and drivers will rely on static signage.
- DVI will remain inactive for a non-RCVW equipped at-grade railroad crossing.
- Positioning correction information may be required for certain sites, such as where a roadway adjacent to and roughly parallel to the railroad has a turn-lane at the intersecting roadway with the at-grade crossing; with this information, the RCVW application might also provide warnings to vehicles turning onto the roadway in the direction of the at-grade crossing when a train is approaching or present.
- Any rail detection equipment not specifically provided or approved by the railroad will be located outside of the railroad right-of-way, i.e., in the public right-of-way, and not be placed on a train, such that there will be added liability and/or maintenance burdens to the rail industry.
- Although the normal operating scenarios include a two-stage alert/warning, there may be circumstances in which the distance to the at-grade crossing is too short to distinguish non-compliant and compliant drivers and there is only sufficient time to issue a warning.
- Current technologies such as radar, positive train control reader (PTC), or RFID reader technology might be possible options for a rail detection system located in the public right-of-way.

6.2.2 Normal Scenario for Equipped Vehicles – No Data from Railroad

For this scenario, an equipped vehicle approaches an at-grade railroad crossing, presumably one that has no dynamic signal warning system. Additionally, a train is either approaching or is already blocking the crossing. Because no data are provided by the train, RSE includes train detection capabilities that are located within the public right-of-way.

Description of Events/Processes

1. An equipped vehicle approaches an RCVW application-enabled at-grade rail crossing and comes in range of the application’s roadside communications.
2. The OBE activates the onboard RCVW application and DVI.

3. The equipped vehicle detects availability of and receives RCVW data:
   - Railroad crossing intersection geometry information, which includes position of the stop bar
   - Positioning system corrections (optional)
   - RWIS data (optional).
4. The equipped vehicle receives and/or updates all static information:
   a. The vehicle decides if it has the current intersection geometry information
   b. The vehicle receives and stores any necessary intersection geometry information in its data store, replacing any older information with updates.
5. The RSE rail detection system located in the public right-of-way detects and tracks all trains in either direction and on all tracks (repeated cycle with steps 6 and 7a).
6. The RSE assesses data from its rail detection system and communicates that and any other available information to the vehicle.
   a. Data might also be transmitted to adjacent active traffic signal for preemption to benefit unequipped vehicles
7. The vehicle application accepts and processes the information.
   a. The RCVW application assesses the status of the rail crossing intersection.
      i. If no train is approaching or present at the intersection to create a conflict with the vehicle, the application continues to assess the status of the rail crossing intersection.
      ii. If a train is approaching or present at the intersection, the RCVW vehicle application performs geospatial matching using the positioning correction information to locate itself relative to the intersection at the road level.
         1. The RCVW application then determines the vehicle speed, and assesses necessary trajectory(s) (the driver may happen to accelerate or decelerate) for the vehicle to prevent a crash from occurring, i.e., to come to a complete stop before the railroad crossing.
8. The RCVW application monitors the vehicle speed and telematics for any corrective action (e.g., braking) to determine whether the driver is responding to the train in a way that will prevent a collision from occurring, issuing an appropriate alert and/or warning on the DVI, if warranted, that is consistent with any automated signage.
   a. At an appropriate distance from the stop bar (i.e., at the railroad crossing warning sign, computed as a function of available data using friction factor, vehicle parameters, roadway geometry, vehicle operating conditions, road and weather information, perception-reaction time, etc.), the RCVW application and DVI may provide an alert to the driver, if deemed necessary by a deceleration algorithm, that it is necessary to stop at a rail crossing ahead. Given RWIS data, this will always be generated in low-visibility conditions.
      i. The distance at which an alert or warning is issued may vary depending upon the available data, i.e., vehicle parameters, weather information, etc.
   b. The RCVW application and DVI may provide a more urgent warning to the driver, if deemed necessary that it is necessary to stop at a rail crossing ahead.

    i. Optional: The vehicle will actively prepare for a possible crash in the vehicle: pre-tensioning of safety belts or priming of brake assistance systems, depending on the individual decisions of the vehicle's OEM.
  c. The roadside rail detection system will continue to monitor all tracks, even after a vehicle has stopped for a passing train. After a train has passed, the RCVW application will automatically issue a warning about a second intersecting train, if applicable.
9. The RCVW application is deactivated after the vehicle has cleared the railroad.

6.2.3 Normal Scenario for Equipped Vehicles – Data from Railroad Signal Warning System

For this scenario, an equipped vehicle approaches an at-grade railroad crossing that has a dynamic signal warning system (i.e., dynamic flashing beacons or gates). Additionally, a train is either approaching or is already blocking the crossing. In this scenario, data are provided by the railroad infrastructure.

Description of Events/Processes

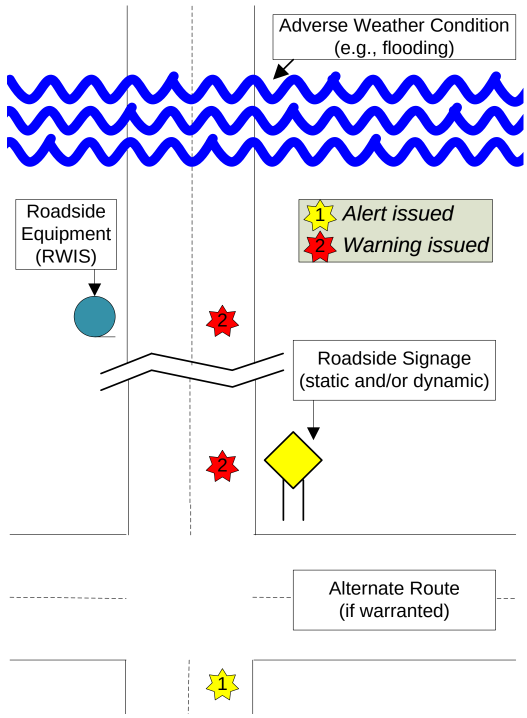
1. An equipped vehicle approaches an RCVW application enabled at-grade rail crossing and comes in range of the application's roadside communications.
2. The OBE activates the onboard RCVW application and DVI.
3. The equipped vehicle detects availability of and receives RCVW data:
    - Railroad crossing intersection geometry information, which includes position of the stop bar
    - Positioning system corrections (optional)
    - Road Weather Information System data (optional).
4. The equipped vehicle receives and/or updates all static information:
    a. The vehicle decides if it has the current intersection geometry information
    b. The vehicle receives and stores any necessary intersection geometry information in its data store, replacing any older information with updates.
5. The RSE receives information from the railroad via the interconnect interface leading to a signal warning system from an track circuits on the railroad and/or connection to adjacent active traffic signal pre-emption) about the presence of trains in the proximity of the railroad crossing (repeated cycle with steps 6 and 7a).
6. The RSE transmits the train presence information and other information, including the activation of any automated signage displays (e.g., flashing beacons), to the vehicle.
7. The vehicle application accepts and processes the information.
    a. The RCVW application assesses the status of the rail crossing intersection.
        i. If no train is approaching or present at the intersection to create a conflict with the vehicle, the application continues to assess the status of the rail crossing intersection.
        ii. If a train is approaching or present at the intersection, the RCVW vehicle application performs geospatial matching using the positioning correction information to locate itself relative to the intersection at the road level.

1. The RCVW application then checks vehicle speed, and assesses necessary trajectory(s) (the driver may happen to accelerate or decelerate) for the vehicle to prevent a crash from occurring, i.e., to come to a complete stop before the railroad crossing

8. The RCVW application monitors the vehicle speed and telematics for any corrective action (e.g., braking) to determine whether the driver is responding to the train in a way that will prevent a collision from occurring, issuing an appropriate alert and/or warning on the DVI, if warranted, that is consistent with any automated signage.
   a. At an appropriate distance from the stop bar (i.e., at the railroad crossing warning sign, computed as a function of available data using friction factor, vehicle parameters, roadway geometry, vehicle operating conditions, road and weather information, perception-reaction time, etc.), the RCVW application may provide an alert to the driver via the DVI, if deemed necessary, to stop at a rail crossing ahead. Given RWIS data, this will always be generated in low-visibility conditions.
      i. The distance at which an alert or warning is issued may vary depending upon the available data, i.e., vehicle parameters, weather information, etc.
   b. At a second, closer distance to the stop bar, the RCVW application and DVI provide a more urgent warning to the driver, if deemed necessary by a deceleration algorithm, that it is necessary to stop at a rail crossing ahead.
      i. Optional: The vehicle will actively prepare for a possible crash in the vehicle: pre-tensioning of safety belts or priming of brake assistance systems, depending on the individual decisions of the vehicle's OEM.
   c. The RSE will continue to monitor data for all railroad tracks, even after a vehicle has stopped for a passing train. After a train has passed, the RCVW application will automatically issue a warning about a second crossing train, if applicable.
9. The onboard RCVW application is deactivated after the vehicle has cleared the railroad.

6.3 Spot Weather Impact Warning

The SWIW application is intended to inform drivers to unsafe conditions at specific points on the downstream roadway as a result of weather-related impacts, which include, but are not limited to high winds, flood conditions, ice, or fog. By its nature as an infrastructure-based application, the SWIW is expected to be deployed at locations that experience frequently recurring weather-related issues. Although the precise timing and algorithm of SWIW-issued advisory messages, alerts, and warnings in relation to the downstream location of the unsafe condition may vary by the severity of the event (e.g., is diversion or only reduced speed recommended?), a general overview of possible locations for advisory messages, alerts, and/or warnings is presented in Figure 6-3.



Source: Battelle

Figure 6-3. Potential SWIW Layout

6.3.1 Preconditions and Assumptions

- The vehicle is en route to a destination via a route with spot weather information.
- In the case of an equipped vehicle, DVI messages will always be consistent with the DII signage.
- In general, as more data are available for a given spot weather warning deployment, the greater confidence that can be placed in recommended advisory, alert, or warning messages, thus reducing the need to potentially connect to the back office TMC for verification of weather condition and validation of recommended message.
- The timing and location for issuing alert or warning messages may vary from what is shown in Figure 6-3. Without certainty of a vehicle's destination, only messages for recommended diversion will be issued

6.3.2 Normal Scenario for Non-equipped Vehicles (DII only)

The scenario below is described from the standpoint of an initial infrastructure-based deployment with DII signage ahead of a selected spot weather impact area. This is a similar operational scenario to one that is currently occurring and most likely to continue to occur in the near term, in which a non-equipped vehicle approaches an area with roadside infrastructure, including a RWIS, which may include equipment like sensors, gauges, anemometers, and/or thermometers to monitor weather of concern, including high winds, precipitation, visibility, stream levels for flooding, etc., and intelligent roadside signage. The RWIS detects a weather-related impact (e.g., reduced visibility due to fog, smoke, or dust; high winds; or adverse surface condition such as flooding or ice) and transmits a message to infrastructure application (and possibly the TMC for verification). The information is processed to determine an appropriate response, then an appropriate message is communicated to the roadside DII signage. The DII signage displays an advisory message, alert, or warning, as necessary, which may include a recommended speed or alternate route for all or select vehicles.

Description of Events/Processes:

1. The non-equipped vehicle approaches a weather impact zone for which a SWIW application exists.
    - The application, including the DII signage, is placed ahead of the weather impact zone in such a way that the vehicle receives, on average, the roadway advisory message, alert, or warning in advance of the zone in enough time for a driver to respond, as necessary.
2. The RWIS monitors weather conditions of concern (e.g., low visibility, high wind speed, precipitation, freezing temperature, high stream levels) and communicates collected data to SWIW infrastructure application.
3. Available infrastructure data, e.g., vehicle speeds (potentially to validate weather conditions or establish recommended advisory speeds), is communicated to the SWIW infrastructure application.
4. The SWIW infrastructure application processes all collected information and compares against pre-determined weather-impact thresholds (e.g., high wind speed, visibility distance, measured precipitation, temperature, vehicle speeds).
5. The SWIW infrastructure application recommends appropriate messages based on pre-determined actions for existing weather impact, which is also dependent upon the location and availability of dynamic signage:

An advisory message or alert may be recommended if adverse weather conditions are at/near the threshold, suspected, or predicted	Example message: "REDUCED VISIBILITY AHEAD, USE CAUTION"
A warning	Example message: "REDUCED VISIBILITY AHEAD, REDUCE SPEED TO 35 MPH"
Targeted warnings may be recommended for vehicles more susceptible to current weather condition (e.g., trucks with high winds, 2-wheel drive vehicles vs. 4-wheel drive vehicles)	Example message: "HIGH WINDS AHEAD, TRUCKS REDUCE SPEED TO 35 MPH"
Targeted diversion may be recommended for select vulnerable vehicles depending on availability of dynamic signage and alternate routes with likely higher quality weather conditions	Example message: "HIGH WINDS AHEAD, TRUCKS USE ALTERNATE ROUTE"
Diversion may be recommended or required depending the severity of the weather impact, the availability of dynamic signage, and availability of passable alternate routes	Example message: "HIGH WATER AHEAD, ROAD CLOSED, USE ALTERNATE ROUTE"

a. The back office TMC verifies the presence of adverse weather conditions before messages are posted.
   i. The SWIW infrastructure application communicates to the back office TMC
      1. Periodic messages at pre-determined intervals confirm normal conditions with current weather information and recommended DII message (or no message)
      2. Breach of pre-determined threshold is immediately reported.
   ii. The back office TMC verifies SWIW status
      1. The back office TMC confirms the appropriateness of recommended DII message (or no message)
      2. The back office TMC overrides system and selects different message (or no message) for DII signage.

6. The SWIW application communicates selected message for posting on DII signage.

6.3.3 Normal Scenario for Equipped Vehicles (DII and DVI)

The scenario below is described from the standpoint of an infrastructure-based deployment with DII signage ahead of a selected spot weather impact area, and with vehicles that are equipped with DVI and possibly additional weather sensors. This operational scenario is an extension of the one above. In this scenario, an equipped vehicle approaches an area with roadside infrastructure, including an infrastructure-based RWIS, which may include several ESS, i.e., sensors, gauges, anemometers, and/or thermometers to monitor weather of concern, including high winds, precipitation, visibility, stream levels for flooding, etc.) and intelligent roadside signage. The RWIS detects a weather-related impact (e.g., reduced visibility due to fog, smoke, or dust; high winds; or adverse surface condition such as flooding or ice) and transmits a message to infrastructure application and the vehicle application. The vehicle communicates any relevant information from onboard sensors to the infrastructure application; this information might be used to either supplement or verify the data collected by the RWIS. The infrastructure application processes available information to determine an appropriate response (which may also be communicated to the TMC for verification). Then an appropriate message is communicated to the vehicle and roadside for display on DII signage. The DII signage and DVI display a consistent advisory message, alert, or warning, as necessary, which may include information regarding recommended speed or alternate routes for all or select vehicles.

Description of Events/Processes:

1. The equipped vehicle approaches a weather impact zone for which a SWIW application exists.
   - The application, including the DII signage, is placed ahead of the weather impact zone in such a way that the vehicle receives the roadway advisory message, alert, or warning in enough time for a driver to respond, as necessary.
   - The OBE activates the onboard SWIW application and DVI
2. The RWIS monitors weather conditions of concern (e.g., visibility, wind speed, precipitation, temperature, stream levels) and communicates collected data to SWIW infrastructure application.
3. The equipped vehicle communicates any relevant, collected weather information and vehicle telematics data (e.g., vehicle speed, headlight status, windshield wiper status) to the SWIW infrastructure application.

4. Other available infrastructure data, e.g., vehicle speeds (potentially to validate weather conditions or establish recommended advisory speeds), are communicated to the SWIW infrastructure application.
5. The SWIW infrastructure application processes all collected information and compares it against pre-determined weather-impact thresholds (e.g., high wind speed, visibility distance, measured precipitation, temperature).
6. The SWIW infrastructure application recommends appropriate messages on available dynamic signage based on pre-determined actions for existing weather impact:

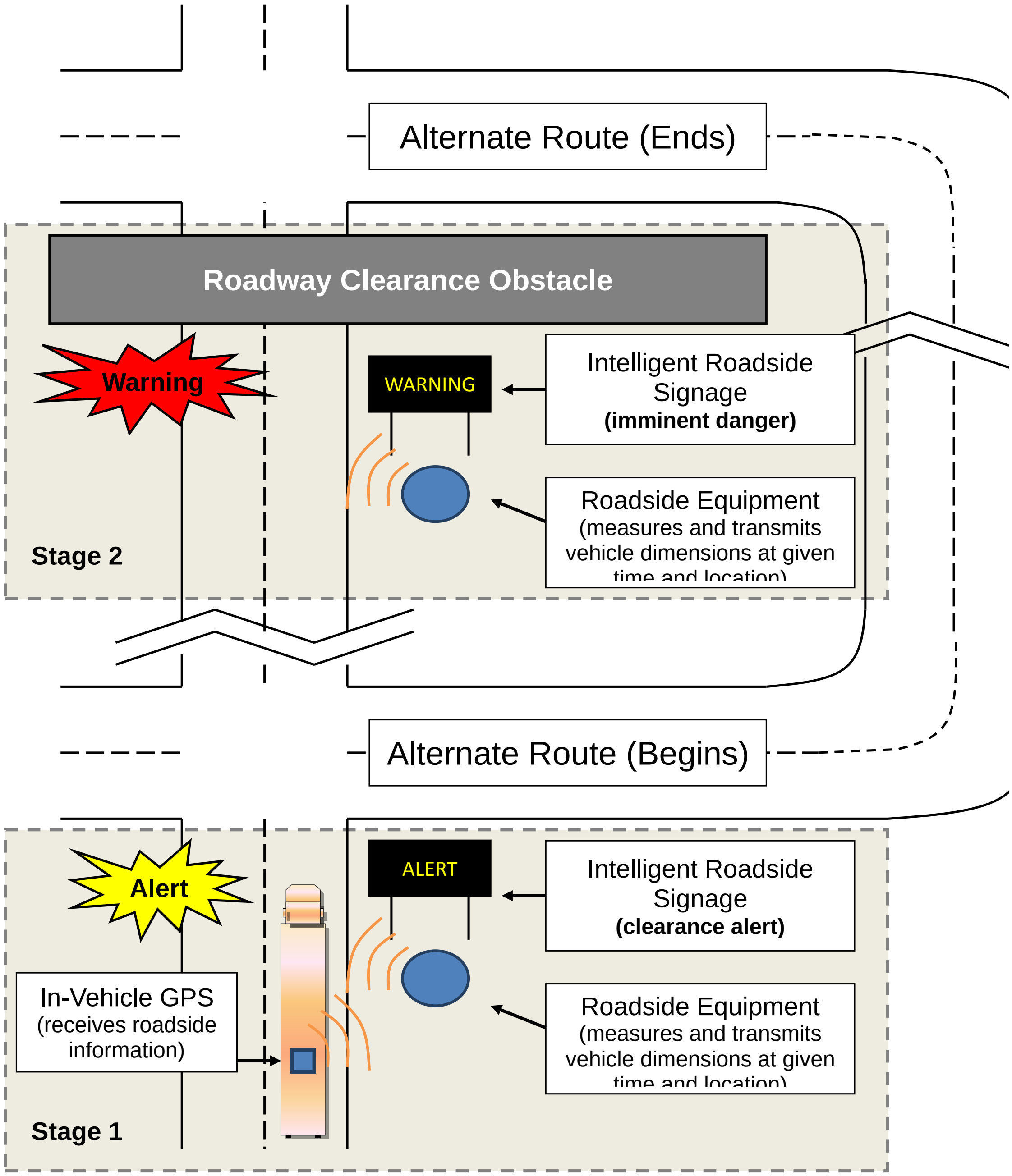
An advisory message or alert may be recommended if adverse weather conditions are at/near the threshold, suspected, or predicted	Example message: "REDUCED VISIBILITY AHEAD, USE CAUTION"
A warning	Example message: "REDUCED VISIBILITY AHEAD, REDUCE SPEED TO 35 MPH"
Targeted warning may be recommended for vehicles more susceptible to current weather condition (e.g., trucks with high winds, 2-wheel drive vehicles vs. 4-wheel drive vehicles)	Example message: "HIGH WINDS AHEAD, TRUCKS REDUCE SPEED TO 35 MPH"
Targeted diversion may be recommended for select vulnerable vehicles depending on availability of dynamic signage and alternate routes with likely higher quality weather conditions	Example message: "HIGH WINDS AHEAD, TRUCKS USE ALTERNATE ROUTE"
Diversion may be recommended or required depending the severity of the weather impact, the availability of dynamic signage, and availability of passable alternate routes	Example message: "HIGH WATER AHEAD, ROAD CLOSED, USE ALTERNATE ROUTE"

   a. The back office TMC verifies the presence of adverse weather conditions before messages are posted.
      i. The SWIW infrastructure application communicates to the back office TMC
         1. Periodic messages at pre-determined intervals confirm normal conditions with current weather information and recommended DII message (or no message)
         2. Breach of pre-determined threshold is immediately reported.
      ii. The back office TMC verifies SWIW status
         1. The back office TMC confirms the appropriateness of recommended DII message (or no message)
         2. The back office TMC overrides system and selects different message (or no message) for DII signage.
7. The SWIW application communicates selected message to the equipped vehicle and DII signage
   a. DII signage posts selected message.

8. The equipped vehicle detects availability of and receives SWIW data, which includes, as available and if applicable for weather conditions:
    a. Message posted on DII
    b. Distance of adverse weather impact zone (throughout which the DVI message should apply)
    c. Weather data collected by the RWIS
    d. (Optional, possibly part of message posted on DII) Infrastructure application recommended advisory speed
    e. (Optional, possibly part of message posted on DII) Infrastructure application recommendation to divert to alternate route.
9. The equipped vehicle SWIW application uses available weather data, vehicle telematics data, and DII message to determine appropriate, consistent message to provide to driver via the DVI, as necessary (if current speed is below the speed limit and/or at the speed recommended in the DII message, a message may not be needed).
10. If driver fails to heed DVI recommendation, the SWIW vehicle application will issue a more urgent warning to the driver via the DVI about adverse conditions ahead (e.g., diversion was recommended and the vehicle proceeds beyond the turnoff for the alternate route, or reduced speed was recommended and vehicle does not reduce speed).
11. After the equipped vehicle has exited the adverse weather impact zone, the SWIW application will deactivate, unless onboard weather sensors determine that a DVI advisory message, alert, or warning is still warranted.

6.4 Oversize Vehicle Warning

The OVW safety application is intended to alert or warn drivers of oversize vehicles, who are approaching a roadway clearance obstacle (e.g., bridge or tunnel) with a vertical clearance height lower than the height of their vehicle or with an inadequate horizontal clearance. The application provides an initial alert to the driver at a decision point for an alternate route in enough time to exit the road or change the vehicle’s direction to avoid the roadway clearance obstacle. If necessary, the application will also provide the driver with a warning, indicating imminent danger, if the vehicle is at the point of approach. The application is intended for all roadway types (e.g., rural roadways, urban environments, interstates). Although the precise timing and algorithm of OVW-issued alerts and warnings in relation to the approaching roadway clearance obstacle has not been determined, a general overview of locations of alerts and warnings in relation to the roadway clearance obstacle is presented in Figure 6-4.



Source: Battelle

Figure 6-4. Oversize Vehicle Warning Layout

6.4.1 Preconditions and Assumptions

- The vehicle is traveling on a route that will lead to a roadway clearance obstacle (e.g., a low height and/or narrow clearance bridge or tunnel)
- The roadway leading up to the roadway clearance obstacle includes static and/or dynamic signage warning the vehicle of the approaching obstacle's low height and/or narrow horizontal clearance.
- There are two sets of roadside signage. The first set of signage is located such that the vehicle will have the opportunity to view the message (as an alert) at a decision point for an alternate route in enough time to exit the road or change the vehicle's direction to avoid the roadway clearance obstacle. The second set is located a short distance before the obstacle (as a warning) to announce to the driver the imminent danger of collision with a low- or narrow clearance ahead.
- Although the normal operating scenarios include a two-stage alert/warning, there may be circumstances in which the distance to the roadway clearance obstacle is too short to distinguish non-compliant and compliant drivers and there is only sufficient time to issue a warning.

6.4.2 Normal Scenario for Non-equipped Vehicles (DII only)

The scenario below is described from the standpoint of an initial infrastructure-based deployment with DII signage ahead of the roadway clearance obstacle . This is a similar operational scenario to one that is currently occurring and most likely to continue in the near term, in which a non-equipped vehicle is driving on a stretch of road ahead of a roadway clearance obstacle equipped with roadside infrastructure, including intelligent roadside signage. The scenario occurs in two stages with two sets of infrastructure equipment. In both stages, the infrastructure application receives information (i.e., height and width of the approaching vehicle) from the infrastructure data equipment, processes it, and communicates this information to the roadside signage. In the first stage, if necessary, the roadside signage displays an alert of the low- or narrow clearance bridge or tunnel on the DII signage. If the vehicle disregards the message and continues along the path toward the roadway clearance obstacle, the second stage of the application displays a warning, indicating imminent danger, near the point of approach.

Description of Events/Processes:

1. The non-equipped vehicle approaches a stretch of roadway for which an OVW application exists.
    a. Roadside equipment with the OVW application, including the DII signage, is placed a distance ahead of a decision point for taking an alternate route for the roadway clearance obstacle in such a way that the vehicle receives the roadway alert ahead of an intersection, exit ramp, or other roadway feature that will allow for easy rerouting.
2. The OVW infrastructure application receives notification of a vehicle's presence from the infrastructure data equipment.
    a. Infrastructure data equipment includes a vehicle detection component that measures the vehicle's dimensions, as necessary.
3. The OVW infrastructure application determines whether an alert is necessary based on the measured vehicle dimensions.

4. If necessary, an alert is issued to the driver before approaching the decision point for an alternate route, providing enough time for the vehicle to exit the road or change its direction to avoid the roadway clearance obstacle.
    a. The OVW infrastructure application provides a message via the roadside signage. The message alerts the vehicle that it is too tall and/or wide to clear the obstacle.
5. The driver of the oversize vehicle responds to or ignores the alert:
    a. Option 1: The driver reads the alert and decides to leave the current roadway, avoiding the roadway clearance obstacle.
    b. Option 2: The driver ignores the alert and continues on its current route toward the roadway clearance obstacle to a destination before the obstacle.
        i. The driver reaches the planned destination, which is after the location of the alert signage but ahead of the roadway clearance obstacle.
    c. Option 3: The driver ignores the alert, continues on the route toward the roadway clearance obstacle, and is given a warning prior to the obstacle.
        i. OVW infrastructure data equipment near the roadway clearance obstacle measures the vehicle's dimensions, as necessary.
        ii. The OVW infrastructure application determines whether a warning is necessary based on the measured vehicle dimensions.
        iii. If necessary, a warning is issued to the driver via the roadside signage. The warning notifies the vehicle that it is too tall or wide to clear the obstacle and a collision is imminent.
        iv. The application sends a notification to applicable agencies (e.g., Department of Public Safety), since the oversize vehicle was detected beyond the last available exit.

6.4.3 Normal Scenario for Equipped Vehicles (DII and DVI)

For this scenario, an equipped vehicle is driving on a stretch of road ahead of a roadway clearance obstacle (e.g., low- or narrow-clearance bridge or tunnel). The scenario below is described from the standpoint of a more mature infrastructure-based deployment with both DII signage and vehicles equipped with a DVI and GPS component, which is an operational scenario that is likely to develop over the longer term. A DVI may consist of display, audio, and/or haptic messages. DVI messages must always be consistent with the DII signage. The in-vehicle GPS is used to capture lane-level roadside information (e.g., vehicle height, width, and the time at a particular location on the roadway). Similar to the DII-only scenario above, this scenario also occurs in two stages with two sets of infrastructure equipment. In the first stage, if necessary, the driver receives both a DVI in-vehicle and DII infrastructure signage alert of the roadway clearance obstacle. If the vehicle disregards the message and continues along the path toward the roadway clearance obstacle, the second stage of the application displays a warning, indicating imminent danger, near the point of approach.

Description of Events/Processes:

1. The equipped vehicle approaches a stretch of roadway for which an OVW application exists.
    a. Roadside equipment with the OVW application, including the DII signage, is placed a distance ahead of a decision point for taking an alternate route for the roadway clearance obstacle in such a way that the vehicle receives the alert ahead of an intersection, exit ramp or other roadway feature that will allow for easy rerouting.

2. The OVW infrastructure application receives notification of a vehicle's presence from the infrastructure data equipment.
    a. The data equipment includes a vehicle detection component that measures (1) the vehicle's dimensions, (2) the time the vehicle is at a particular (lane level) roadway location, and (3) the lane level roadway location coordinates.
3. The vehicle receives information from the OVW infrastructure application regarding (1) roadway clearance obstacle geometry, (2) the vehicle's measurements (as determined by the roadside equipment), and (3) the time the vehicle was at the roadway location where the measurements were taken.
    a. Transmitted information includes the clearance dimensions of the roadway clearance obstacle, geospatial information regarding the position of the roadway clearance obstacle along the roadway, the vehicle's current dimensions, and geospatial (lane-level) data regarding position of the truck at given timestamp.
        i. The in-vehicle GPS timestamp is used by the vehicle to determine that the measurements provided by the infrastructure are for the specific vehicle. (This is necessary in the event that multiple oversize vehicles are passing through one location).
    b. The obstacle's clearance dimensions will be transmitted with sufficient frequency to support the application safety objectives.
4. The vehicle stores this information in its OVW vehicle application.
5. The OVW vehicle application processes the infrastructure and vehicle information.
6. The OVW vehicle application assesses whether the vehicle's dimensions exceed the obstacle's clearance dimensions.
7. As necessary, an alert is issued to the driver before approaching the decision point for an alternate route, providing enough time for the vehicle to exit the road or change its direction to avoid the roadway clearance obstacle.
    a. The onboard DVI system will alert the driver in sufficient time to reroute the vehicle safely.
    b. The DII signage will also illuminate an alert message indicating that the vehicle's dimensions exceed the obstacle's clearance.
8. The driver of the oversize vehicle responds to or ignores the alert
    a. Option 1: The driver sees the alert and decides to leave the current roadway, avoiding the roadway clearance obstacle.
    b. Option 2: The driver ignores the alert and the vehicle continues on its current route toward the roadway clearance obstacle to a destination before the obstacle.
        i. The driver reaches the planned destination, which is after the location of the initial alert but ahead of the roadway clearance obstacle.

c. Option 3: The driver ignores the alert, the vehicle continues on its current route toward the roadway clearance obstacle, and the vehicle is given a warning prior to the obstacle via (1) a second set of OVW infrastructure equipment and (2) the OVW vehicle application.
   i. OVW infrastructure application response:
      1. OVW infrastructure data equipment near the roadway clearance obstacle measures the vehicle's dimensions, as necessary.
      2. The OVW infrastructure application determines whether an alert is necessary based on the measured vehicle dimensions.
      3. If necessary, a warning is issued to the driver via the roadside signage. The warning notifies the vehicle that it is too large to clear the obstacle and a collision is imminent.
      4. The application sends a notification to applicable agencies (e.g., Department of Public Safety) since the oversize vehicle was detected beyond the last available exit.
   ii. OVW vehicle application response:
      1. The OVW vehicle application tracks the vehicle position relative to the location of the roadway clearance obstacle.
      2. At an appropriate distance in advance of the roadway clearance obstacle, the DVI will issue a warning to the driver. The warning notifies the vehicle that it is too tall or wide to clear the obstacle and a collision is imminent.

6.5 Reduced Speed/Work Zone Warning

The Reduced Speed Zone warning (RSZW) safety application is intended to alert or warn drivers who are approaching a reduced speed zone if (1) they are operating at a speed higher than the zone's posted speed limit and/or (2) the configuration of the roadway has altered (e.g., lane closures, lane shifts). Reduced speed zones include (but are not be limited to) construction/work zones, school zones, and incorporated zones (e.g., rural towns). Although the precise timing and algorithm of RSZW-issued alerts and warnings in relation to the approaching reduced speed zone have not been determined, a general overview of locations of alerts and warnings in relation to the zone is presented in Figure 6-4.

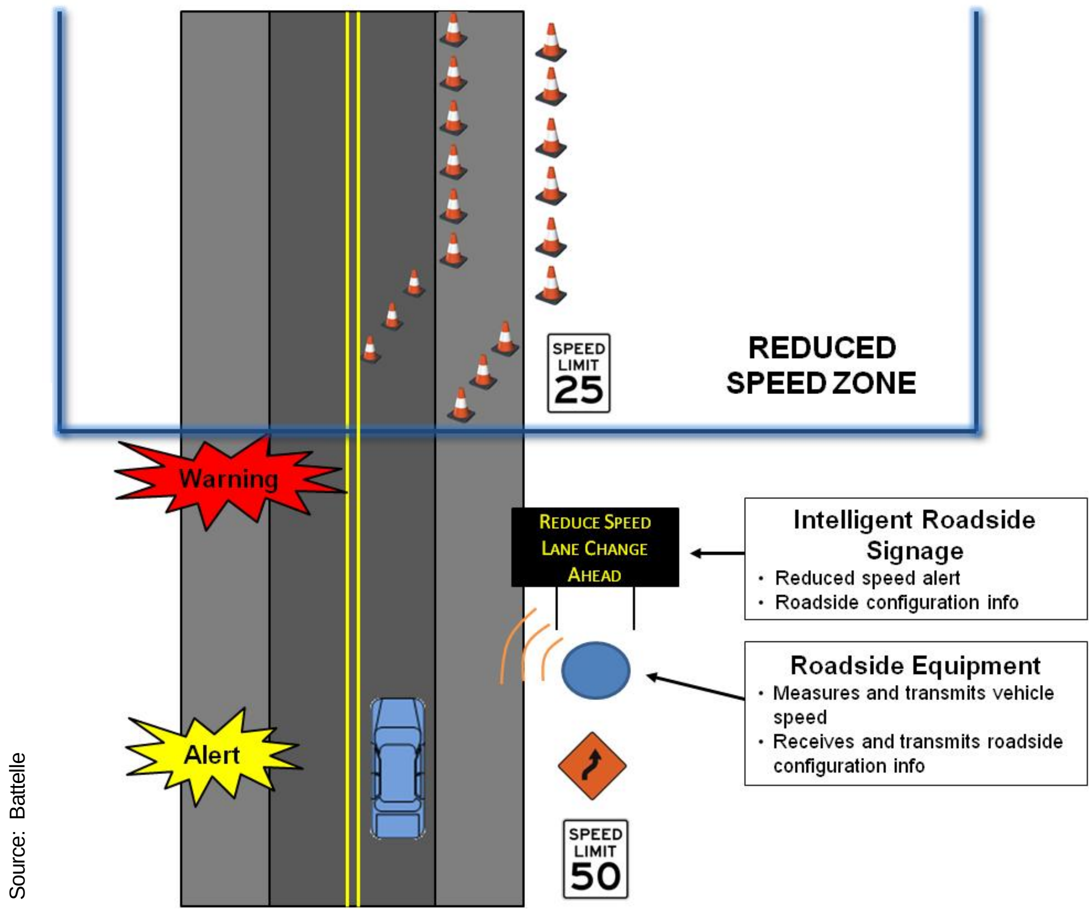


Figure 6-5. RSZW Layout

6.5.1 Preconditions and Assumptions

- The vehicle is traveling on a route that will require it to drive through a reduced speed zone.
- The reduced speed zone is marked with a posted speed limit.
- The application is intended for regulatory speed limits.
- The ”reduced speed zone” category encompasses any segment of roadway that is subject to reduced speeds, which includes but is not limited to construction/work zones, school zones, and incorporated zones.
- Some reduced speed zones, such as a school zone, may only be applicable for specific times of day, days of week, or seasonal changes in speed.
- In the case of a work zone, the work zone may be susceptible to both speed reductions and roadway configuration changes (e.g., lane closures, lane shifts).
- The roadway leading up to the reduced speed zone includes static and/or dynamic signage warning the vehicle of the reduced speed (and when necessary roadway configuration changes).
- The term “back office,” specifically as it pertains to work zones, refers to an external interface that can provide input to the infrastructure application and/or DII and may be a wired or remote

connection to a TMC, field office, or person in the field depending upon site specific conditions and equipment.

- MUTCD signage should be used as appropriate.
- Although the normal operating scenarios include a two-stage alert/warning, there may be circumstances in which the distance to the reduced speed zone is too short to distinguish non-compliant and compliant drivers and there is only sufficient time to issue a warning.

6.5.2 Normal Scenario: Non-Equipped Vehicles (DII only) for Speed Reductions Only

The scenario below is described from the standpoint of an initial infrastructure-based deployment with DII signage ahead of a reduced speed zone. This speed zone scenario is limited to speed reductions and does not incorporate roadway configuration changes. This is a similar operational scenario to one that is currently occurring and most likely to continue to occur in the near term, in which a non-equipped vehicle approaches a reduced speed zone equipped with roadside infrastructure. The infrastructure application receives information from the infrastructure data equipment, processes it, and communicates this information to the roadside signage. The roadside signage displays a warning on the DII signage, if necessary.

Description of Events/Processes:

1. The non-equipped vehicle approaches a reduced speed zone for which a RSZW application exists.
    a. The application, including the DII signage, is placed ahead of the reduce speed zone in such a way that the vehicle receives the roadway warning in enough time for a driver to reduce speed, if necessary.
    b. The roadside equipment is programmed (as necessary) with multiple speed limits for variations by time of day, day of week, or season of year.
        i. In the case of a school zone, speed limits vary based on when school is in session, which may be specific to time of day (e.g., from 8 AM to 3 PM the posted speed limit is 20 MPH, from 3:01 PM to 7:59 AM the posted speed limit is 35 MPH), day of week (e.g., Monday-Friday versus Saturday and Sunday), and seasonal (e.g., September-May versus June-August) constraints.
2. As a vehicle approaches the reduced speed zone, the roadside infrastructure detects and measures the vehicle’s current speed.
3. The RSZW infrastructure application determines whether a warning is necessary based on the measured vehicle speed and the current posted speed limit.
4. If necessary, an alert or warning is issued to the driver via the RSZW DII signage.
    a. The RSZW infrastructure provides a message via the roadside DII signage. The message indicates that the vehicle’s speed exceeds the posted speed limit.

6.5.3 Normal Scenario: Equipped Vehicles (DII and DVI) for Speed Reductions Only

For this scenario, an equipped vehicle approaches a reduced speed zone. This speed zone scenario is limited to speed reductions and does not incorporate roadway configuration changes. The scenario below is described from the standpoint of a more mature infrastructure-based deployment with both DII signage and vehicles equipped with a DVI, which is an operational scenario that may develop over the longer term. A DVI may consist of display, audio, and/or haptic messages. Note that the DII may be directed at a specific vehicle, but in general it cannot be assumed to be directed at a specific vehicle (like DVI is).

Description of Events/Processes:

1. The equipped vehicle approaches a reduced speed zone for which a RSZW application exists.
    a. The infrastructure application is placed ahead of the reduced speed zone in such a way that the vehicle receives the infrastructure-based and vehicle-based warnings in enough time for a driver to reduce speed, if necessary.
    b. The RSE is programmed (as necessary) with multiple speed limits for variations by time of day, day of week, or season of year.
        i. In the case of a school zone, speed limits vary based on when school is in session, which may be specific to time of day (e.g., from 8 AM to 3 PM the posted speed limit is 20 MPH, from 3:01 PM to 7:59 AM the posted speed limit is 35 MPH), day of week (e.g., Monday-Friday versus Saturday and Sunday), and seasonal (e.g., September-May versus June-August) constraints.
2. As a vehicle approaches the reduced speed zone, the roadside infrastructure detects, measures, and records the vehicle's current speed.
3. The RSZW infrastructure transmits relevant information to the RSZW vehicle application where the information is stored.
    a. Transmitted information includes the posted speed limit (based on time-of-day) and current DII message.
    b. Reduced speed zone information will be transmitted with sufficient frequency to support the application safety objectives. Frequency is determined by the vehicle's ability to receive and process the information and issue a warning in enough time for a driver to reduce speed, if necessary.
4. The vehicle retrieves its current speed and position from its vehicle data systems.
5. The RSZW infrastructure and vehicle applications independently capture and assess available infrastructure and vehicle information to determine whether the current operating speed exceeds the posted speed limit for the reduced speed zone.
6. As necessary, an alert or warning is issued to the driver via the RSZW infrastructure equipment by the infrastructure application and the RSZW DVI by the vehicle application.
    a. The onboard DVI warning system will alert or warn the driver to reduce the vehicle's speed in sufficient time before entering the reduced speed zone. The warning may be aural, visual, and/or haptic.
    b. The DII signage will illuminate an alert or warning message. The message displayed indicates that the vehicle's speed exceeds the posted speed limit.

6.5.4 Normal Scenario: Non-Equipped Vehicles (DII only) for Speed Reductions and Changed Lane Configurations

The scenario below is described from the standpoint of an initial infrastructure-based deployment with DII signage ahead of a reduced speed zone. This speed zone scenario includes both speed reductions and roadway configuration changes (e.g., lane closures, lane shifts). It is more likely to occur in a work zone rather than a school or incorporated zone. Other applications of this scenario include a permanent lane change configuration; for example, a 4-lane divided freeway that transitions to a lower-speed two-lane undivided roadway, particularly if the lane change configuration is new. This is a similar operational scenario to one that is currently occurring and most likely to continue to occur in the near term, in which a non-equipped vehicle approaches a reduced speed zone equipped with roadside infrastructure. The infrastructure application receives information from the infrastructure data equipment, processes it, and communicates this information to the roadside signage. The roadside signage displays a warning on the DII signage, if necessary.

Description of Events/Processes:

1. The non-equipped vehicle approaches a reduced speed zone for which a RSZW application exists.
    a. The application, including the DII signage, is placed ahead of the reduced speed zone in such a way that the vehicle receives the roadway warning in enough time for a driver to reduce speed and maneuver lane closures and/or shifts, if necessary.
    b. The roadside equipment is programmed (as necessary) with multiple speed limits for variations by time of day, day of week, or season of year.
        i. In the case of a school zone, speed limits vary based on when school is in session, which may be specific to time of day (e.g., from 8 AM to 3 PM the posted speed limit is 20 MPH, from 3:01 PM to 7:59 AM the posted speed limit is 35 MPH), day of week (e.g., Monday-Friday versus Saturday and Sunday), and seasonal (e.g., September-May versus June-August) constraints.
        ii. Some work zones have reduced speeds only when workers are present, which may be specific to time of day (e.g., from 7 AM to 5 PM the posted speed limit is 55 MPH, from 5:01 PM to 6:59 AM the posted speed limit is 65 MPH) or day of week (e.g., Monday-Friday versus Saturday and Sunday)
2. The infrastructure receives real-time roadway configuration information from the back office, as necessary.
    a. As changes occur to the roadway configuration (e.g., lane shifts, lane closures), the organization responsible for reporting this information provides it to the back office. The information is transmitted, in real-time, to the appropriate RSZW infrastructure equipment.
    b. Configuration information is sent to the RSZW application and resides in the RSZW infrastructure application as current, until the back office provides a new roadway configuration to the RSE.
3. As a vehicle approaches the reduced speed zone, the roadside infrastructure detects and measures the vehicle's current speed.
4. The RSZW infrastructure application assesses available information regarding lane configuration and vehicle speed and determines the appropriate message to display on DII

signage. A warning may be necessary based on the measured vehicle speed and the current posted speed limit; otherwise only a lane configuration alert is given.

a. If the vehicle is speeding, a warning is issued to the driver via the RSZW DII signage along with roadway configuration information:

    i. The RSZW infrastructure provides a message via the roadside signage. The DII message indicates that the vehicle's speed exceeds the posted speed limit, as well as relevant roadway changes.

b. When the vehicle is not speeding, the RSZW DII signage posts only roadway configuration information:

    i. The RSZW infrastructure provides a message on the DII regarding relevant roadway changes.

6.5.5 Normal Scenario: Equipped Vehicles (DII and DVI) for Speed Reductions and Changed Lane Configurations

For this scenario, an equipped vehicle approaches a reduced speed zone. This speed zone scenario includes both speed reductions and roadway configuration changes (e.g., lane closures, lane shifts). It is more likely to occur in a work zone rather than a school or incorporated zone. Other applications of this scenario include a permanent lane change configuration; for example, a 4-lane divided freeway that transitions to a lower-speed two-lane undivided roadway, particularly if the lane change configuration is new. The scenario below is described from the standpoint of a more mature infrastructure-based deployment with both DII signage and vehicles equipped with a DVI, which is an operational scenario that is likely to develop over the longer term. A DVI may consist of display, audio, and/or haptic messages. Note that the DII may be directed at specific vehicle, but in general it cannot be assumed to be directed at a specific vehicle (like DVI is). In addition to messages about speed reduction and roadway configuration changes, warnings may also be given via the DVI if position correction information is available to detect vehicles in a lane that is about to end who are calculated to be too quickly approaching the merge point and in danger of crashing into a barrier and/or the work zone itself.

Description of Events/Processes:

1. The equipped vehicle approaches a reduced speed zone for which a RSZW application exists.

    a. The infrastructure application is placed ahead of the reduced speed zone in such a way that the vehicle receives the infrastructure-based and vehicle-based warnings in enough time for a driver to reduce speed, if necessary.

    b. The roadside equipment is programmed (as necessary) with multiple speed limits for variations by time of day, day of week, or season of year.

        i. In the case of a school zone, speed limits vary based on when school is in session, which may be specific to time of day (e.g., from 8 AM to 3 PM the posted speed limit is 20 MPH, from 3:01 PM to 7:59 AM the posted speed limit is 35 MPH), day of week (e.g., Monday-Friday versus Saturday and Sunday), and seasonal (e.g., September-May versus June-August) constraints.

        ii. Some work zones have reduced speeds only when workers are present, which may be specific to time of day (e.g., from 7 AM to 5 PM the posted speed limit is 55 MPH, from 5:01 PM to 6:59 AM the posted speed limit is 65 MPH) or day of week (e.g., Monday-Friday versus Saturday and Sunday)

2. The infrastructure receives real-time roadway configuration information from the back office, as necessary.
    a. As changes occur to the roadway configuration (e.g., lane shifts, lane closures) the organization responsible for reporting this information provides it to the back office. The information is transmitted, in real-time, to the appropriate RSZW infrastructure equipment.
    b. Configuration information is sent to the RSZW application and resides in the RSZW infrastructure application as current, until the back office provides a new roadway configuration to the RSE.
3. As a vehicle approaches the reduced speed zone, the roadside infrastructure detects, measures, and records the vehicle's current speed.
4. The RSZW infrastructure transmits relevant information to the RSZW vehicle application where the information is stored.
    a. Transmitted information includes the posted speed limit (based on time of day, day of week, etc.), roadway configuration and geometry information, and current DII message.
    b. Reduced speed zone information will be transmitted with sufficient frequency to support the application safety objectives. Frequency is determined by the vehicle's ability to receive and process the information and issue a warning in enough time for a driver to reduce speed, if necessary.
5. The vehicle retrieves its current speed and position from its vehicle data systems.
6. The RSZW infrastructure and vehicle applications independently capture and assess available infrastructure and vehicle information to assess whether the current operating speed exceeds the posted speed limit for the reduced speed zone. The infrastructure and vehicle applications determine the appropriate message to display on DII signage and DVI, respectively. A warning may be necessary based on either a comparison between measured vehicle speed and the current posted speed limit, or (if applicable) a vehicle is approaching the merge point in a lane that is about to end and the application calculates that a crash is imminent given current speed and distance to the end of the lane. Otherwise only a lane configuration alert is given.
    a. Option given position correction information: A warning is issued to the driver via DVI by the RSZW vehicle application if the vehicle is in a lane that is about to end and, given speed and distance to the end of the lane (i.e., merge point), the application calculates that a crash is imminent.
    b. If the vehicle is speeding, a warning is issued to the driver via DII by the RSZW infrastructure application and DVI by the RSZW vehicle application, along with roadway configuration information.
        i. The RSZW infrastructure provides a message via the DII roadside signage. The message indicates that the vehicle's speed exceeds the posted speed limit, as well as relevant roadway changes (e.g., "left lane closed ahead, merge right").
        ii. The onboard warning system will warn the driver to reduce the vehicle's speed in sufficient time before entering the reduced speed zone. The warning may be aural, visual, and/or haptic. The DVI will also provide

relevant roadway configuration information (e.g., “left lane closed ahead, merge right”).

c. When the vehicle is not speeding, the RSZW infrastructure and RSZW vehicle application provide only roadway configuration information.
   i. The RSZW infrastructure provides a message via the DII regarding relevant roadway changes (e.g., “left lane closed ahead, merge right”).
   ii. The RSZW vehicle application provides a DVI message regarding relevant roadway changes (e.g., “left lane closed ahead, merge right”).

7.0 Summary of Impacts

Implementation of these V2I safety applications: SSVW, RCVW, SWIW, OVW, and RSZW supports the USDOT's connected vehicle safety application deployment. The subsections below identify potential operational impacts, organizational impacts, and impacts during the development of the applications.

7.1 Operational Impacts

This section describes the impacts that the safety applications will have on both the entities developing, installing, operating, and maintaining the applications as well as the application users within the connected vehicle environment.

The most significant operational impact of these applications is their effect on increased roadway safety. Expected benefits include:

- Reductions in the number of roadway fatalities
- Reductions in the number and severity of roadway injuries
- Reductions in property damage associated with roadway incidents
- Reductions in the number of near-miss intersection conflict and run-off-road (ROR) incident scenarios.

Additional benefits may include:

- The development of a safety warning system that is deployable nationwide and found to be acceptable, understood, and useful to users, so as to elicit timely and appropriate driver response
- The development of a connected vehicle environment in which emerging technologies can utilize existing infrastructure to enhance safety benefits (eventually incorporating V2V concepts)
- The deployment of technology systems to establish a foundation of communication and technologies that will bridge the gap between current roadway safety conditions with non-equipped vehicles and a saturated connected vehicle environment
- Continued promotion of the institutional relationship between the public (e.g., U.S., state, and local DOTs) and private sectors (e.g., vehicle manufacturers) to further promote transportation safety.

Below is a description of operational impacts by user groups.

7.1.1 Driver Impacts

There will be several minor impacts on drivers in the deployment of V2I safety applications. The greatest impact is that drivers will receive real-time warnings while driving based on their current driving conditions. Warnings include:

- Warning of a stop sign at an stop-controlled intersection (SSVW)
- Warning of an approaching or crossing train (RCVW)
- Warning of hazardous weather-related conditions (SWIW)
- Warning of a roadway clearance obstacle (e.g., low and/or narrow clearance bridge/tunnel) (OVW)
- Warning to reduce speed and for changes to roadway configuration (RSZW).

This information should result in safer trips with fewer incidents at stop sign controlled intersections, at-grade railroad crossings, roadways prone to adverse weather conditions, geometrically constrained infrastructure, and roadways with reduced speed limits. Each safety application is designed to provide drivers with a combination of haptic, visual, and/or audio warnings in an effective format that does not distract or overwhelm them. These warnings are designed to be presented to drivers in a timeframe that provides adequate reaction time to either:

- Reduce speed to stop at a stop sign (SSVW),
- Stop at an at-grade railroad crossing for an approaching or crossing train (RCVW),
- Reduce speed or divert from a roadway in response to a hazardous weather-related impact, such as reduced visibility, adverse surface conditions, or high winds (SWIW),
- Reroute an oversize vehicle to avoid a roadway clearance obstacle (e.g., low and/or narrow clearance bridge/tunnel) (OVW), or
- Reduce speed and/or be aware of changed roadway configurations heading into a reduced speed zone (RSZW).

Drivers will be responsible for maintaining application components within their vehicles, as needed.

It is expected that drivers will modify their driving behaviors in response to the applications' intended purposes, thus creating a safer driving environment. However, as drivers become more accustomed to the safety applications, behavior may change as drivers rely more on the application and potentially assume a less active role in driving defensively. Becoming desensitized to and ignoring provided warnings is an example of a modified behavior that would compromise the safety benefits expected from these applications.

7.1.2 State and Local Government/DOT Impacts, including Railroad Companies

State and local governments and their respective DOTs will be impacted by the installation and maintenance of V2I safety applications roadside infrastructure, located along roadways within their jurisdictional authority. Similar impacts may be incurred by railroad companies for the installation and maintenance of infrastructure needed for the RCVW application. Installation and maintenance may require additional staff and resources, and impact the roadways due to necessary road closures. Governments and/or DOTs will be responsible for all infrastructure-related actions (e.g., repair and maintenance), including the communication network. It is reasonable to assume that governments and/or DOTs will also be responsible for providing users with real-time data from pre-existing roadside systems (e.g., RWIS), as needed to enable the functionality of any of these V2I safety applications.

7.1.3 USDOT Impacts

The USDOT's role in connected vehicle applications includes providing high-level guidance to state and local agencies in the development and operation of V2I safety applications. The USDOT's responsibility to continually provide guidance will impact the agency due to the monetary and human resources necessary for the task. It is also expected that the USDOT will be, in cooperation with the standards development organizations (e.g., SAE, ASSHTO, NEMA, IEEE), responsible for connected vehicle guidelines and standards.

7.1.4 Equipment Manufacturers

Automobile OEMs are responsible for the development and maintenance of any vehicle-related equipment and software necessary to establish and maintain the V2I safety applications. As the applications are deployed and mature, OEMs will be responsible for the continual upgrade and improvement of all new vehicle-related hardware and software components for each V2I safety application (while drivers will be responsible for ongoing hardware or software upgrades on already-purchased vehicles). OEMs will be impacted by the need for dedicated resources for this continuous, large-scale task. Similar responsibilities may be expected from aftermarket safety device manufacturers and traffic control equipment manufacturers.

7.2 Organizational Impacts

This section addresses the impacts the new system will have on operators of the V2I safety applications.

The organizational impacts of this proposed system include additional responsibilities for the installation, configuration, operation, and maintenance of both the roadside infrastructure and onboard application systems. These responsibilities fall on the State and local agencies and automobile OEMs, respectively. State and local agencies will require new tools and systems to assist them in implementing the roadside system. These agencies will need additional funding and operational support to deploy these systems in wide-scale deployments.

The State and local agency staff and OEM staff responsible for the V2I safety applications, as well as any additional required staff to support the additional infrastructure, will require training. Training should include classroom and hands-on training (for each application) as well as operations and maintenance training. Classroom training provides staff with the ConOps, relationships, features, and an introduction to the hardware and software interfaces. Hands-on training allows staff to work with hardware components and software applications to practice basic operator and maintainer tasks.

7.3 Impacts During Development

This section addresses the impacts that users and operators will experience during the development of these V2I safety applications.

Major impacts are not expected during the development of these applications. The most likely impacts encountered during the development of the applications will be the need to identify communication methods and potentially modify communication standards (e.g., DSRC). New data elements, message sets, and data flows are likely to be identified and will need to be incorporated into existing standards.

Additional impacts may include the following:

- Development of rules and controls needed for operational implementation
- System documentation updates
- Involvement in studies, meetings, and discussions prior to design and implementation
- Involvement in reviews and demonstrations
- Evaluation of revised operating capabilities
- Development or modification of safety applications, and required training
- Coordination with state and local agencies
- Possible additional staff to support development by state and local agencies
- Possible roadway closures to support development.

8.0 Analysis of the Proposed System

The subsections below identify the improvements, disadvantages and limitations, and alternatives and trade-offs associated with the development and deployment of the proposed connected vehicle V2I safety applications: SSVW, RCWV, SWIW, OVW, and RSZW.

8.1 Summary of Improvements

The five connected vehicle V2I safety applications will provide new capabilities for detecting and warning motorists about potential unsafe conditions at stop sign controlled intersections, at-grade railroad crossings, roadways prone to hazardous weather-related conditions, geometrically constrained infrastructure (e.g., bridges and tunnels), and reduced speed zones. Through these connected vehicle applications, equipped vehicles and the roadside infrastructure can share information in real time that will help drivers to negotiate roadways more safely. The applications will also increase situational awareness for drivers.

All five applications provide improvements from the current, largely non-equipped vehicle environment:

- **Stop Sign Violation Warning:** SSVW aids drivers by warning a driver at a stop sign controlled, stop-controlled intersection prior to the point where the vehicle would be unable to safely stop for the stop sign. Thus, the application will reduce the number of vehicles exposed to cross-traffic due to intersection violations. At the same time, the application may reduce the number of rear-end crashes caused when a distracted driver suddenly becomes aware of the upcoming stop sign and sharply brakes too quickly for the driver in the following vehicle to respond before a crash. Unlike current systems that may include static signage or flashing beacons that warn a driver of a stop sign, SSVW will provide onboard warning to the driver based on any data available, including current vehicle operating conditions and roadway conditions.
- The SSVW application also includes the capability of capturing specific intersection geometries either in real time via roadside equipment or with onboard storage. The application is dynamic and can consider any data available for current road and weather conditions along with other available vehicle telematics data to calculate a more accurate stopping distance. The application monitors vehicle deceleration rates, comparing with the necessary rate for a safe, required stop at a stop sign. The warning system will provide a warning within sufficient time for the driver to receive and react to it. At the same time, the application will remain silent and inactive when the driver's speed remains below a deceleration threshold, when a stop is necessary; this is to avoid nuisance alerts and/or warnings and increase user acceptance and application effectiveness.
- **Railroad Crossing Warning:** RCVW aids drivers by warning of an approaching or crossing train at an at-grade railroad crossing prior to the point where the vehicle would be unable to safely stop for the train. Thus, the application will warn distracted drivers of conflicting trains and reduce the number of vehicles exposed to oncoming or passing trains due to railroad

crossing violations. Unlike current systems that may include dynamic signal warning systems with flashing beacons and/or gates, RCVW will provide onboard warnings to the driver based on data available, which may include train presence, current vehicle operating conditions, and roadway conditions.

- The RCVW application also includes the capability of capturing train presence with or without participation from railroad companies by utilizing either information obtained from the railroad interconnect interface leading to a signal warning system from track circuits on the railroad (i.e., the assumed situation for signalized at-grade railroad crossings), or with a separate, roadside-based train detection system located in the public right-of-way (e.g., using radar, lidar, cameras, or, depending on technologies utilized by the railroad industry, positive train control (PTC) reader or RFID reader; the assumed situation for at-grade railroad crossings without signal warning systems), respectively. The application is dynamic and can utilize any data available for current road and weather conditions along with other available vehicle telematics data to calculate a more accurate stopping distance. The application monitors vehicle deceleration rates, comparing with the necessary rate for a safe, required stop at a railroad crossing with an approaching or crossing train. The warning system will provide a warning within ample time for the driver to receive and react to it. At the same time, the application will remain silent and inactive when the driver's speed remains below a deceleration threshold, when a stop is necessary; this is to avoid nuisance alerts and/or warnings and increase user acceptance and application effectiveness.
- **Spot Weather Information Warning:** SWIW aids drivers by advising, alerting, or warning a driver of hazardous weather-related conditions. Thus, the application will increase driver awareness of weather-related conditions, such as reduced visibility (e.g., fog, smoke), adverse road surface conditions (e.g., due to flooding, rain, ice, snow, etc.), or high winds. The application may reduce the number of rear-end crashes caused when drivers travel faster than the speed of downstream drivers during reduced visibility, or run-off road crashes due to reduced visibility, adverse surface conditions, or high winds. The application will provide messages to the driver regarding adverse weather conditions, after obtaining validation from a back office TMC, that may include recommendations for reduced speed and/or diverting to an alternate route, depending upon the severity of the weather impact. Unlike current systems that may include static or dynamic signage, SWIW will also provide onboard messages to the driver based on data available, including current vehicle operating conditions and roadway conditions.
- Overall, this application varies from the others in that it is not necessarily warning the driver about a crash-imminent scenario so much as hazardous conditions that may pose a higher risk for an incident occurring. The warning system will only be functional when spot weather data are available for areas prone to adverse weather conditions, and will remain silent and inactive when the driver's speed remains below an acceptable threshold, given current conditions; this is to avoid nuisance alerts and/or warnings and increase user acceptance and application effectiveness.
- **Oversize Vehicle Warning:** OVW aids drivers by preventing oversize vehicles from colliding into geometrically restricted infrastructure, such as low and/or narrow clearance bridges and tunnels. OVW-related collisions may result in injuries and fatalities as well as infrastructure damage or collapse. Such crashes can be extremely costly. Unlike current warnings, which provide a static low or narrow clearance warning ahead of a bridge or tunnel, the OVW provides a two-stage alert/warning system capable of capturing the vehicle's real-time measurements and warning the vehicle in enough time to reroute and avoid the roadway clearance obstacle.

- The OVW application includes the capability of capturing specific vehicle measurements (width, height, timestamp, and location) via the RSE. This allows for real-time determination of clearance levels. The accuracy of the OVW application allows for cleared vehicles to pass through the roadway clearance obstacle that would otherwise be unable to due to conservative clearance levels that are posted on static signage. Additionally, the real time measurements provide an added layer of safety to vehicles with profiles that may have unknowingly changed and would otherwise have been susceptible to collision.
- **Reduced Speed/Work Zone Warning:** RSZW aids drivers by reducing the potential for speed and roadway configuration related crashes in reduced speed zones, including those that may involve pedestrians. RSZW crashes affect motorists as well as construction workers (in work zones) and children (in school zones) along with other drivers and passersby. Unlike current systems that may include static or dynamic signage that warns drivers to reduce their speed with school zone signs that flash or when construction workers are present, the RSZW will provide both roadway and onboard warnings to the driver based on real-time roadway conditions.
- The RSZW application includes the capability of capturing specific time-of-day, day-of-week, and seasonal information via the roadside equipment. It is also able to capture real-time roadway configuration changes via the back office. This provides the most accurate roadway conditions to drivers. The application allows for better preparation and awareness of drivers when approaching reduced speed zones, and can provide a warning to vehicles that are in a lane that is about to end, have not yet merged, and are judged to be crash-imminent.

In addition to the specific benefits discussed above, benefits common to all five applications include:

- Accommodation of a full range of drivers, including inexperienced and older drivers
- Compatibility with all types of vehicle classes
- Functionality in all weather and lighting conditions
- Universal design for effective performance in urban, suburban, and rural areas
- Accuracy and precision to issue alerts/warnings when warranted and avoid false indications
- Integration of current onboard safety systems and future connected vehicle systems
- Integration of human factors guidelines
- Reports of off-line system components
- Alerts to users of security breaches and privacy invasion.

8.2 Disadvantages and Limitations

This section provides a summary of the disadvantages and/or limitations of the proposed safety applications. The safety applications being proposed are intended for a fully functional connected vehicle environment, which does not currently exist. While several regions have begun to develop policies and infrastructure around connected vehicle technology systems, a fully saturated environment is decades away. Due to this reality, the safety applications being suggested are capable of functioning in a mixed environment in which surrounding vehicles may or may not be equipped and in areas where infrastructure does not currently exist. In such areas the warning systems, which rely on connected roadside infrastructure, will not be functional. The result of this merged environment is that the added benefits of these applications will not be fully realized, and additional infrastructure investments will likely be necessary to detect and/or incorporate non-equipped vehicles.

In addition, equipped vehicles are likely to cost slightly more than comparable non-equipped vehicles. This may result in lower income groups being less likely to drive an equipped vehicle. This issue will likely need to be resolved early on to avoid any potential social equity issues around roadway safety.

Another impact of the mixed environment is the potential for contradictory warning messages between existing warning systems and the newer connected vehicle V2I safety applications. For example, if an equipped vehicle with SWIW capabilities is driving along a roadway with a static roadside warning sign, the driver may be driving slower than the advisory or posted speed displayed on the static sign. However, due to the real-time calculations that the V2I safety application is capable of for specific vehicles and weather conditions, the vehicle warning system may calculate the driver's speed to be too high and issue a warning to slow down. While it can be reasonably assumed that the V2I safety applications are more accurate, to drivers this may provide confusing messages and reduce the potential safety benefit.

Currently the application design is set up in such a way that warning decisions are made by the vehicle. The roadside equipment only provides data for the vehicle to manipulate. The result is that all warnings are dependent on the application programming, whether through the OEM or the aftermarket. It is likely that the OEMs will have proprietary technology, similar but unique to each manufacturer. The result is that the technology may not be uniform across vehicle makes and there may be difficulties in eventually leveraging these applications in a V2V format. These potential limitations should be mitigated by appropriate early planning and buy-in with the necessary stakeholders involved.

Currently, there is no deployment schedule for these applications. Design decisions and stakeholder agreements may create delays in deployment in the near future. Moreover, a disadvantage of a cooperative system is that it only works when both the infrastructure and the vehicle are equipped. There are challenges in getting multiple vehicle manufacturers and thousands of infrastructure operators to all agree to consistently deploy these cooperative applications.

8.3 Alternatives and Trade-offs Considered

During the development of the ConOps, several alternatives and trade-offs have been considered that will affect the definition of the safety applications. These include:

- **Role of the Roadside Infrastructure:** Specifically, whether the infrastructure will play an active role in warning the driver of an impending roadway hazard or whether the infrastructure will play a passive role in providing an equipped vehicle with the data necessary to determine if a warning is needed. In evaluating the potential impact of roadside decisions and the possible effects of this responsibility on the State and local agencies accountable for the equipment, it was determined that in-vehicle warning decisions for the applications will be made by the vehicle, with data supplemented by the roadside infrastructure.
- **Effect of the Mixed Environment:** The safety applications will need to function in an environment in which there are non-equipped vehicles and roadways lacking roadside infrastructure to communicate with the onboard system. The result is that the level of investment being made to develop connected vehicle technologies will not result in equal

safety benefits for several years. Safety benefits will not be fully realized until the connected vehicle environment is saturated.

- **SSVW Application Considerations:**
    - The requirement of RSE at all SSVW equipped intersections was considered, but deemed unnecessary given the availability of reliable, frequently updated intersection data from other RSE in other locations.
    - Given a lack of RSE at an SSVW equipped intersection, a method of authenticating or certifying the accuracy of the data will be necessary. Although changes to intersection configuration may be rare, such a change could create unsafe circumstances and cause collisions.
    - For intersections that undergo changes in geometric configurations or traffic control, the presence of RSE, if only temporarily, is recommended as a way to ensure accuracy of data for the SSVW equipped intersection.
    - The SSVW application is currently intended only to provide a warning to equipped vehicles of a potential violation. The application does not warn other drivers in a conflicting path of the impending violation, nor does it actively control a violating vehicle (e.g., active braking). These are all potential options for consideration a future case scenario or other, related applications.
    - Other safety applications may be active at an intersection or in the area, and the SSVW application is intended to accommodate other applications, such as stop sign gap assist (SSGA).

- **RCVW Application Considerations:**
    - This application is considered for situations where the railroad companies are or are not willing to share information regarding train presence. Independent roadside train detection systems might be incorporated in situations where railroad-provided information regarding train presence is unavailable.
    - Road vehicle conflicts with on-street light-rail transit vehicles operating in mixed traffic were considered for inclusion in the RCVW application. However, due to complexities with data required for the application to function in this scenario, this was removed from consideration.
    - Only at-grade railroad crossings for railroads with separate rights-of-way were considered as possible locations to employ the RCVW application.
    - Other safety applications may be active in the area, and the RCVW application is intended to work in conjunction with other applications, such as RLVW or SSVW, in the situation where an at-grade rail crossing is adjacent to a roadway intersection, for example.

- **SWIW Application Considerations:**
    - A variety of weather-related impacts and conditions are included as possible focus areas for this application, including but not limited to reduced visibility due to fog, smoke, or smog; adverse roadway surface conditions caused by flooding, rain, snow, or ice; and high winds.
    - Back office validation is required for this application to issue alerts and warnings to the vehicle given the general lack of reliability in ESS. As applications become more reliable, this requirement may be removed. Alternatively, the use of redundant ESS

or RWIS and/or vehicle data, e.g., speed, were considered for automated validation of recommended messages.

- Message specificity was considered for this application: “reduce speed” versus recommended advisory speeds versus enforceable variable speeds, and “use alternate route” versus more specific routing information. Final message options will depend upon a variety of factors such as confidence in available data, site-specific policies regarding variable speeds, availability of reliable alternate routes, and availability of in-vehicle navigation systems.
- Vehicle-based weather sensors were considered as a possibility for future vehicle fleets, but ultimately are not likely for the near term.
- Given lack of network-wide road weather information, in the near term, this application is limited to warnings for spot weather impacts in areas with high probability of hazardous conditions.
- Warnings for a queue or forward collision are not considered for this application, as these are more likely to be related V2V applications.
- Other safety applications may be active in the area, and the SWIW application is intended to function in conjunction with other applications.
- Because weather impacts are less “crash imminent” than other safety applications presented here, the SWIW application also incorporates advisory messages to simply present information to drivers, as a less urgent message than the two-stage alert and warning approach used in the other safety applications.

- **OVW Application Considerations:**
  - The OVW application is descriptive and requires the driver to determine how to avoid the roadway clearance obstacle. The OVW application does not include navigation for rerouting.
  - The OVW application provides DII- and DVI-based warnings to indicate to the driver imminent danger of an oversize vehicle collision. The application does not include active vehicle systems such as automatic braking when the risk of collision is present.
  - The OVW application is intended to provide alerts and/or warnings to oversize vehicles for a single roadway clearance obstacle or consecutive roadway clearance obstacles in a segment of roadway. The application does not include alerts and/or warnings for multiple non-consecutive roadway clearance obstacles.
  - The OVW application uses infrastructure-based vehicle measurements. Oversize vehicle drivers may not have access to accurate vehicle measurements and/or the vehicle dimensions may be susceptible to change. Therefore, the OVW infrastructure application conducts real-time measurements in advance of the roadway clearance obstacle and provides measurements to the OVW vehicle application.
  - The OVW application includes two sets of roadside signage to alert and if necessary warn the driver. The potential for a long distance between the first alert and the second warning could result in the inability of the technology to transmit vehicle information between the two sets of equipment.
  - Other safety applications may be active in the area, and the OVW application is intended to function in conjunction with other applications.

- **Reduced Speed Zone Application Considerations:**
  - The RSZW application is descriptive and expects the driver to react when notified of a change to the roadway configuration.
  - Back office interface was determined as necessary, but given the variety of current technologies, specificity regarding location of the back office, i.e., a TMC, field office, or in-person requirement, cannot be finalized.
  - Warnings for a queue or forward collision are not considered for this application, as these are more likely to be related V2V applications.
  - Other safety applications may be active in the area, and the RSZW application is intended to function in conjunction with other applications.

9.0 Notes

9.1 Acronyms and Abbreviations

AAHSTO	American Association of State Highway and Transportation Officials
AAMVA	American Association of Motor Vehicle Administrators
ATIS	Advanced Traveler Information Systems
ATM	Active Traffic Management
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
Caltrans	California Department of Transportation
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CICAS	Cooperative Intersection Collision Avoidance Systems
CICAS-V	Cooperative Intersection Collision Avoidance System Violations
CMV	Commercial Motor Vehicle
ConOps	Concept of Operations
CVO	Commercial Vehicle Operations
DII	Driver-Infrastructure Interface
DMS	Dynamic Message Sign
DOTs	Departments of Transportation
DSDS	Dynamic Speed Display Signs
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
ECUs	Electronic Control Units
ESS	Environmental Sensor Station

EWDS	Early Warning Detection Systems
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FISMA	Federal Information Security Management Act
FRA	Federal Railroad Administration
GID	Geometric Intersection Design
GPS	Global Positioning System
HRI	Highway-Rail Intersection
ICWS	Intersection Conflict Warning Systems
ID	Intersection's Identification
IDOT	Illinois Department of Transportation
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
IVI	Intelligent Vehicle Initiative
JPO	Joint Program Office
LACMTA	Los Angeles County Metropolitan Transportation Authority
LED	Light-Emitting Diode
LOS	Level of Service
MTA	Mass Transit Administration (Maryland)
MUTCD	Manual on Uniform Traffic Control Devices
NBI	National Bridge Inventory
NEMA	National Electrical Manufacturers Association
NHTSA	National Highway Traffic Safety Administration
NYSDOT	New York State Department of Transportation
OBD2	On Board Diagnostics II

OBE	Onboard Equipment
ODOT	Oregon Department of Transportation
OEMs	Original Equipment Manufacturers
OMCC	Office of Motor Carrier Compliance
OVW	Oversize Vehicle Warning
PTC	Positive Train Control
QPLs	Qualified Parts Lists
RCVW	Railroad Crossing Violation Warning
RITA	Research and Innovative Technology Administration
RLVW	Red-Light Violation Warning
ROR	Run-off-Road
RPM	Revolutions Per Minute
RSE	Roadside Equipment
RSZW	Reduced Speed Zone Warning
RV	Recreational Vehicle
RWIS	Road Weather Information System
SAD	System Architecture Document
SAE	Society of Automotive Engineers
SEMP	Systems Engineering Management Plan
SOI	System of Interest
SPE	Speed-Photo-Enforcement
SSGA	Stop Sign Gap Assist
SSVW	Stop Sign Violation Warning
SUVs	Sports Utility Vehicles
SWIW	Spot Weather Information Warning
TDOT	Tennessee Department of Transportation
TEA-21	Transportation Equity Act for the 21st Century

TMC	Traffic Management Center
TTI	Texas Transportation Institute
USDOT	United States Department of Transportation
UTRC	University Transportation Research Center
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDIM	Vehicle Dimension in Motion
VDOT	Virginia Department of Transportation
VII	Vehicle Infrastructure Integration
VSC2	Vehicle Safety Communications 2
VTrans	Vermont Agency of Transportation
VTTI	Virginia Tech Transportation Institute

9.2 Terms and Definitions

Advisory message – an informative message to the driver regarding current roadway conditions; less urgent, i.e., not necessarily crash-imminent, than an alert or warning.

Alert – a cautionary message about an anticipated crash scenario and/or vehicle conflict; more urgent than an advisory message, less urgent than a warning.

Connected vehicle – In the context of this document, refers to the methods, data and technologies used in the bi-directional exchange of information between infrastructure and vehicles for purposes of improving safety, mobility and environmental conditions.

Mandatory – describes a user need that is deemed essential and central for the successful deployment of the V2I safety application(s).*Optional* – describes a user need that is important, but may not be necessary depending on the type of deployment (e.g., DII-only, DII and DVI, or DVI-only) or specific deployment location of the V2I safety application(s).

Perform - to work in a manner to achieve the desired outcome.

Physical Security – describes measures that are designed to deny access to unauthorized personnel (including attackers or even accidental intruders) from physically accessing a building, facility, resource, or stored information; and guidance on how to design structures to resist potentially hostile acts.[57] Physical security can be as simple as a locked door on a roadside cabinet.

Prohibitive Reference Frame – indicates when *unsafe* conditions are present, as opposed to "safe" conditions; "unsafe" is much easier to quantify than "safe," indicates the requirement that users also apply their own judgment, and can lessen liability issues as compared to indicating a more definitive 'permissive' notification of when conditions are "safe".

Rural – All territory, population, and housing units located outside of urbanized areas usually considered anything outside of an area with a population of 5,000 or greater.

Suburban – Part of an urbanized area immediately surrounding the core, metropolitan center of the urbanized area. Generally consists of a population of greater than 5,000 and a population density greater than 500 people per square mile.

Sub-Rural – Generally considered as the area immediately outside of an urbanized area but whose population density is less than 500 people per square mile.

Threshold – A point in both time and/or location, depending on the specific application, that the application would reach a decision point resulting in an action being taken. This action would typically be expected to include alerts and/or warnings issued to the driver, but could also include additional actions.

[57] Task Committee; Structural Engineering Institute (1999). *Structural Design for Physical Security*. ASCE. ISBN 978-0-7844-0457-7.

Urban Area – A densely settled area that has a census population of at least 50,000, generally consisting of a geographic core of block groups or blocks that have a population density of at least 1,000 people per square mile, and adjacent block groups and blocks with at least 500 people per square mile.[58]

Recent Vehicle Position and Time History – Array of recent (of the order of the last few seconds) vehicle position and time data that is compared to infrastructure-based vehicle size, position, and time measurements to identify oversize vehicles.

Vehicle Type – Identification of vehicle role (e.g., ambulance, police cruiser, maintenance vehicle, etc.) as specific class of vehicle satisfies in the surface transportation system. A specific, standardized nomenclature does not exist.

Vehicle Class – One of 13 FHWA designations of motorized vehicles ranging in size from a Class 1 Motorcycle through a Class 13 – Seven or more axle truck.[59]

Warning – an urgent message for a more immediate, potentially crash imminent scenario and/or vehicle conflict; more urgent than both an advisory message and alert.

[58] Glossary for 2000 U.S. Census http://www.census.gov/geo/www/tiger/glossary.html

[59] Traffic Monitoring Guide, USDOT, May 2001, http://www.fhwa.dot.gov/ohim/tmguide/tmg4.htm#app4c

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