Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications

Concept of Operations Document

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16. Abstract

This document describes the concept of operations for three connected vehicle V2I safety applications related to intersection safety and speed management. Specifically, these applications include:

- Red-Light Violation Warning (RLVW)
- Stop Sign Gap Assist (SSGA)
- Curve Speed Warning (CSW)

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A	5/29/2012	Post Walkthrough version	Entire Document
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Executive Summary

This document describes the Concept of Operations (ConOps) for three 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 and roadway safety as it pertains to horizontal curves; 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 three connected vehicle V2I safety applications related to intersection and roadway safety; these applications are described in more detail below and include:

- *Red-Light Violation Warning (RLVW)* – Application designed to warn drivers that they may violate an upcoming red light based on their speeds and distance to the signalized intersection.
- *Stop Sign Gap Assist (SSGA)* – Application designed to warn stopped drivers at a stop-controlled intersection of oncoming cross-traffic.
- *Curve Speed Warning (CSW)* – Application designed to warn drivers that the vehicle's current speed may be too high to safely traverse one or more upcoming curves.

Presently, many infrastructure-based countermeasures have been implemented by public agencies and vehicle-based countermeasures have been implemented by vehicle OEMs, both for the purpose of improving safety. These systems, until recently, have not typically integrated these infrastructure and vehicle data. Integrating roadside infrastructure and vehicle data and systems can provide a richer information set for identifying driving hazards and providing more accurate and timely warnings to drivers of unsafe conditions on the roadway. 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 SysReq for three 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 five other V2I safety applications: Stop Sign Violation Warning (SSVW), Railroad Crossing Violation Warning (RCVW), Spot Weather Information Warning (SWIW), Oversize Vehicle Warning (OVW), and Reduced Speed/Work Zone Warning (RSZW), which were presented in a separate ConOps document. 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 these other supporting ConOps are included as Appendices to this document. This ConOps is limited to describing the expected functionality, operation, and rationale for development of the three safety applications listed above.

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

Red-Light Violation Warning (RLVW)

The objective of RLVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at signalized intersections by providing a warning to the vehicle driver that, based on their speeds and distance to the intersection, they may violate an upcoming red light. An equipped vehicle approaching an equipped intersection receives messages about the signal phase and timing, intersection geometry, and position correction information. The driver is issued a warning if the application determines that, given current operating conditions, the driver is predicted to violate the red light. Figure ES-1 illustrates the proposed RLVW application design.

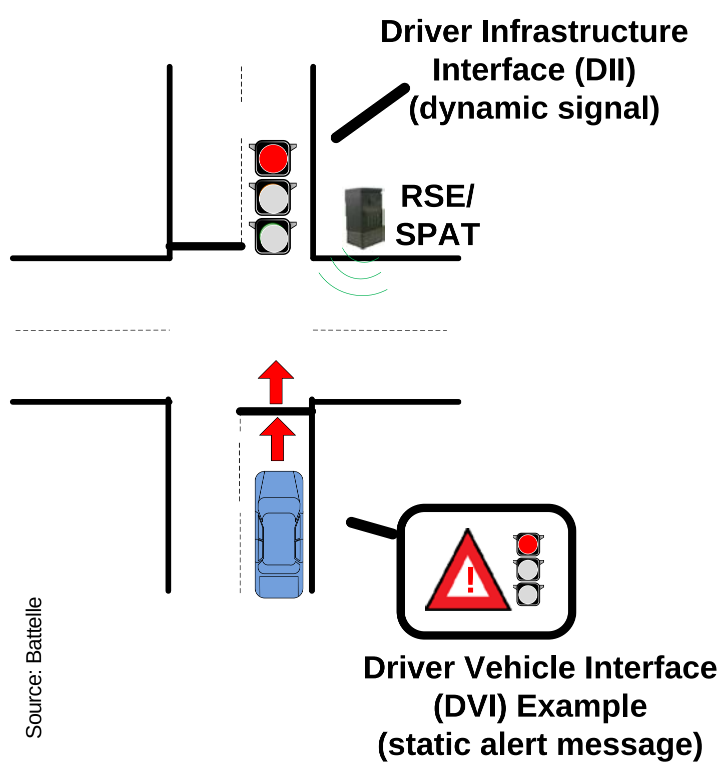


Figure ES-1. RLVW Illustration

Stop Sign Gap Assist (SSGA)

The objective of SSGA is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes by providing approaching cross-traffic information to support driver decisions in safely traversing stop-sign controlled intersections. The system will support stopped minor-road drivers in identifying unsafe gaps in cross-traffic at major road intersections. The infrastructure application will collect available infrastructure and vehicle data, most importantly from the major road vehicle detection system that detects the presence, distance, and speed of each vehicle within its coverage zone. The infrastructure application will process available data to post an appropriate advisory message, alert, and/or warning on the driver infrastructure interface (DII) signage when conditions are determined to be unsafe for minor road drivers to proceed into the intersection. An equipped vehicle stopped at an equipped stop-controlled intersection receives messages from the roadside equipment and will display an appropriate advisory message, alert, and/or warning for the driver on the in-vehicle driver vehicle interface (DVI). Figure ES-2 illustrates the proposed SSGA application design.

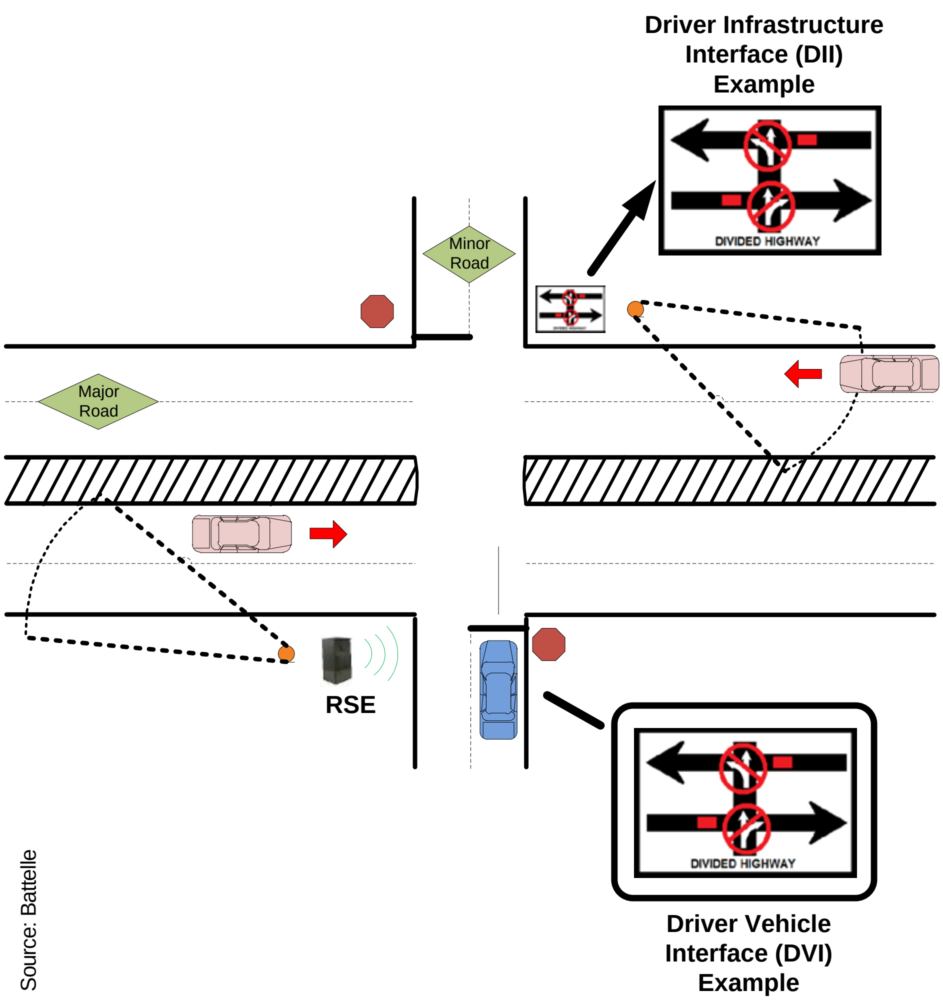


Figure ES-2. SSGA Illustration

Curve Speed Warning (CSW)

The objective of CSW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes by warning the vehicle driver that the vehicle's current speed may be too high to safely traverse one or more upcoming curves. The infrastructure application component will collect available infrastructure and vehicle data, potentially from basic radar detection sensors or a combination of multiple types of sensors (e.g., radar and environmental sensors), then process available data to recommend an appropriate advisory message, alert, and/or warning to provide messages to drivers via DII signage. An equipped vehicle approaching an equipped curve receives messages from the roadside equipment and will display an appropriate advisory message, alert, and/or warning for the driver on the in-vehicle DVI. Figure ES-3 illustrates the proposed CSW application design.

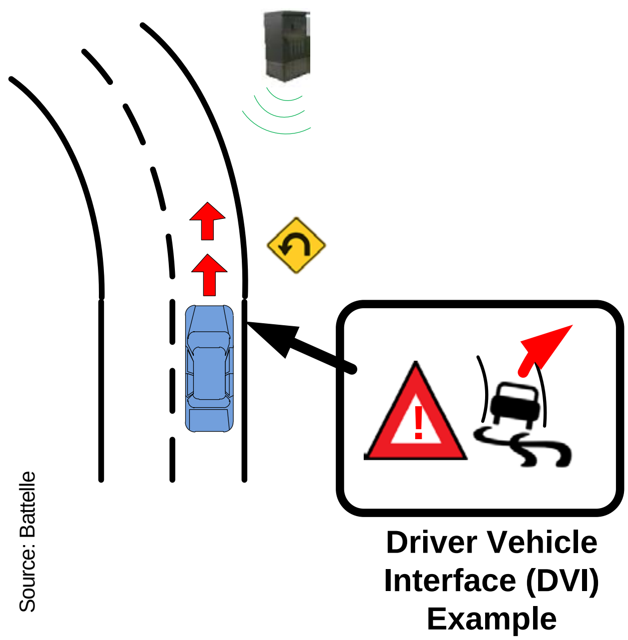


Figure ES-3. CSW Illustration

Benefits

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 and unsafe speeds for roadway curves.
- 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 step-by-step descriptions of how the proposed system might operate and interact with its users and its external interfaces under various given sets 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. 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 previous 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.

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)
    - Speed Management (i.e., curve speed 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
- Disseminate the ConOps to connected vehicle stakeholders and organizations that may implement systems based on the connected vehicle safety concept.

The connected vehicle V2I safety applications project was divided into two phases. Phase I consisted of establishing the baseline policies and procedures that guide the conduct of the program. Phase II consisted of developing the ConOps document.

1.1 Document Identification

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

- Red-Light Violation Warning (RLVW)
- Stop Sign Gap Assist (SSGA)
- Curve Speed Warning (CSW)

These safety applications are sub-components of the larger connected vehicle program, which will produce other ConOps documents related to safety and mobility. This ConOps is limited to describing the expected functionality, operation, and rationale for existence of the three safety applications listed above. This document is partly derived from the Crash Avoidance Metrics Partnership (CAMP) Cooperative Intersection Collision Avoidance System limited to Stop Sign and Traffic Signal Violations (CICAS-V) ConOps and the University of Minnesota Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) ConOps documents, and much of the content from these documents is included here in its original or modified context for clarity and continuity.[1]

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; and
- 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.

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

The intended audience of this ConOps document includes: application developers; automotive, wireless, and ITS equipment OEMs; State and local DOTs; 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 and speed on rural, suburban, and urban roadways.

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 by describing how they interact.

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.

Appendix A provides Engineering Reference Formulas for Curve Speed Warning.

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 and speed management. 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 applications respectively. This same figure also shows external inputs in to the system. The Onboard Platform captures sensor data through the OBD2 and Controller Area Network (CAN) networks for use by the applications. The Road Side Platform capture collects roadside data such as signal controller and road weather information for use by applications. Diagrams specific to individual safety applications are presented later in this document.

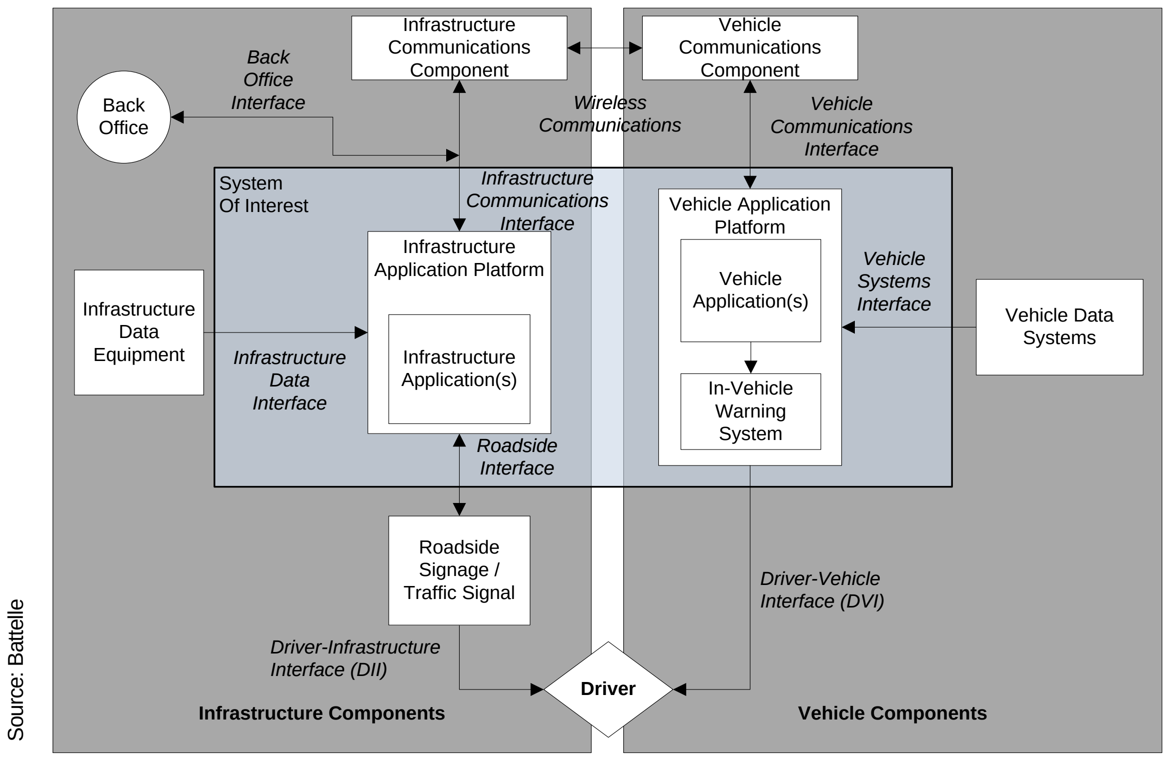
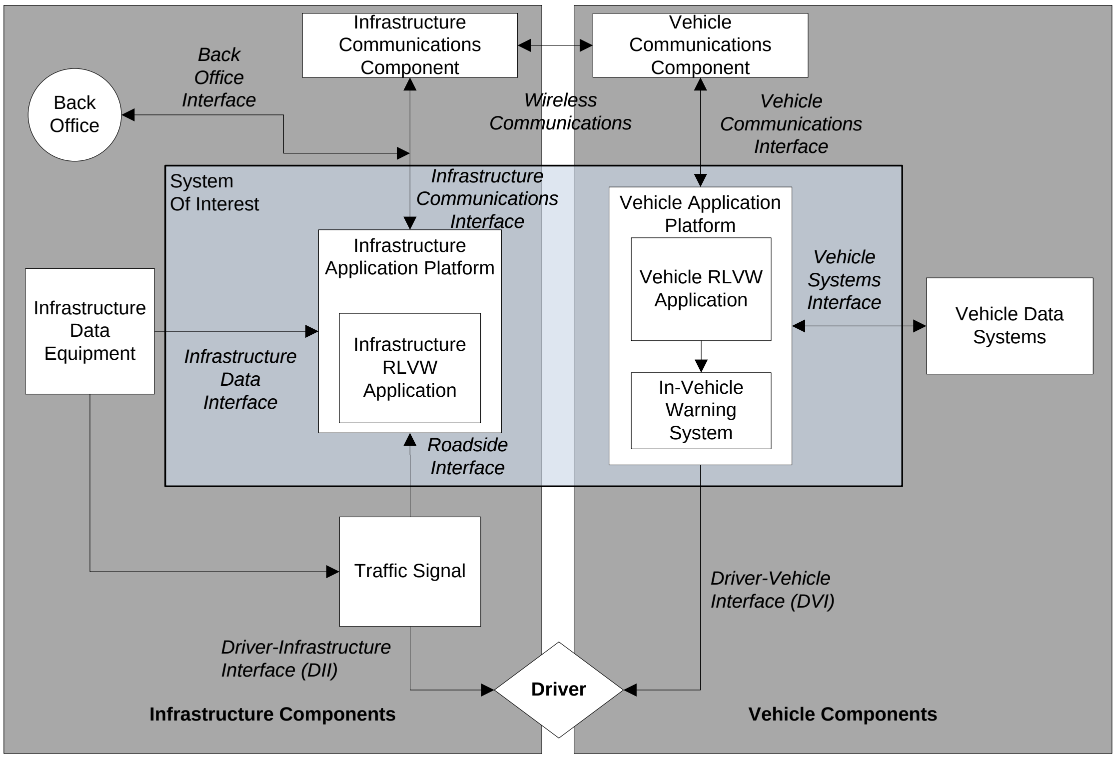


Figure 1-1. General Framework for Connected Vehicle V2I Safety Applications

1.3.1 System of Interest – Red Light Violation Warning Application

The RLWV application is intended to improve safety at signalized intersections through the integration of vehicle-based and infrastructure-based technologies to help drivers approaching an intersection understand the state of activities within that intersection. In particular, signal phase and timing (SPaT) information will inform drivers of a red or impending red light in time to bring the vehicle safely to a stop. This application will thus have the potential to warn drivers about likely violations of traffic signal devices. Figure 1-2 summarizes the proposed RLVW application design.

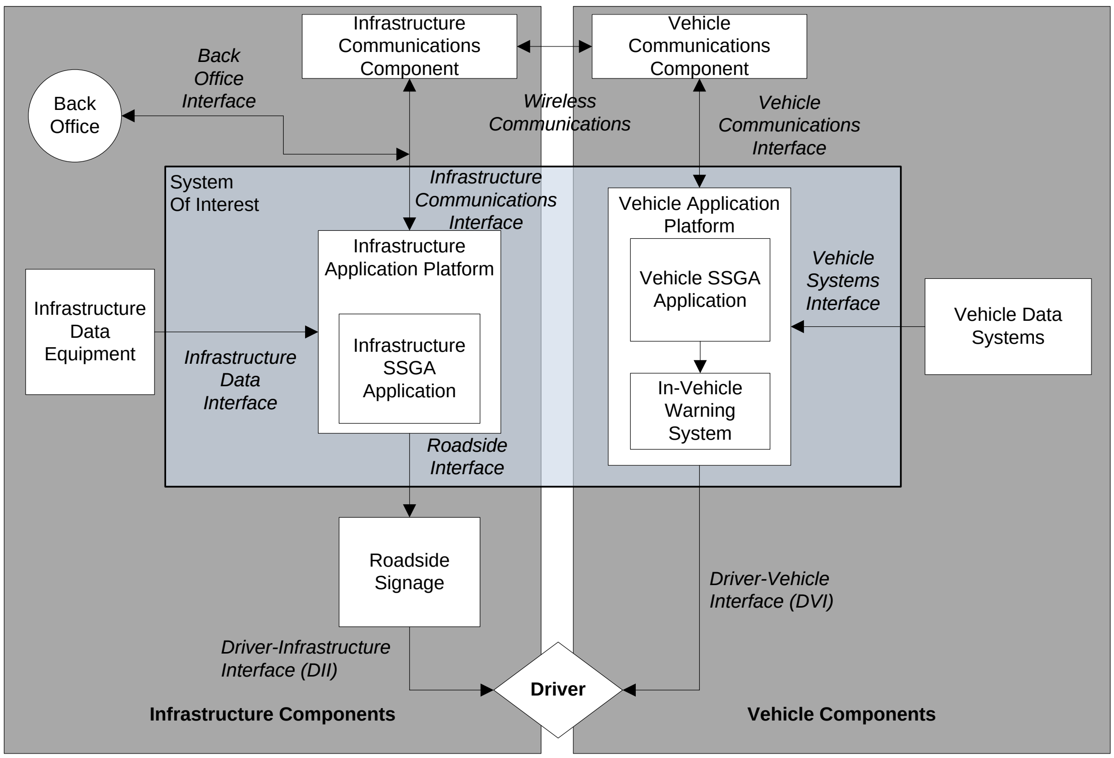


Source: Battelle

Figure 1-2. Red-Light Violation Warning Application Diagram

1.3.2 System of Interest – Stop Sign Gap Assist Application

The SSGA safety application is intended to improve safety at non-signalized intersections where only the minor road has posted stop signs. The will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including both onboard and roadside signage warning systems, to help drivers stopped at an intersection understand the state of activities within that intersection by providing a warning of unsafe gaps on the major road to drivers stopped on a minor road. In this way, the SSGA safety application will help drivers maneuver through cross traffic, reducing the number of conflicts and crashes. The SSGA is unique among the applications presented here in that it is configured for both equipped and non-equipped scenarios, and thus the vehicle components of the application can be optional. Figure 1-3 summarizes the proposed SSGA application design.

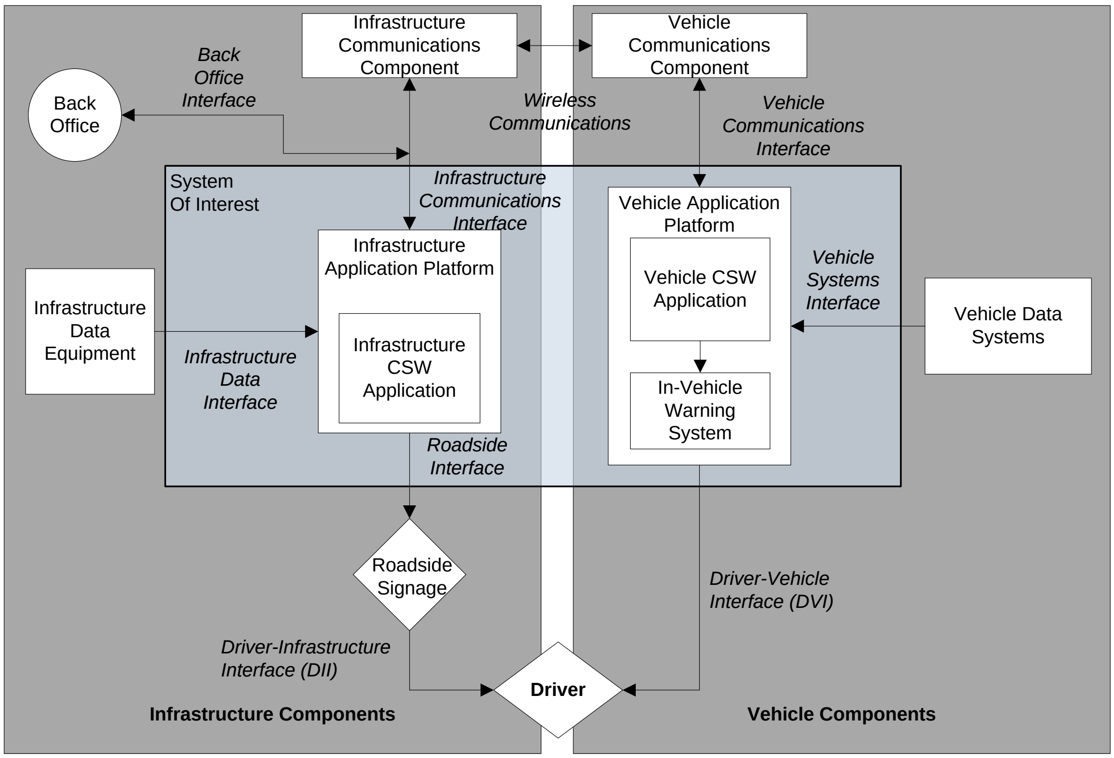


Source: Battelle

Figure 1-3. Stop Sign Gap Assist Application Diagram

1.3.3 System of Interest – Curve Speed Warning Application

The CSW safety application is intended to improve safety when traversing curves through the integration of vehicle-based and infrastructure-based technologies to help drivers approaching a curve travel through it at a safe speed based on the current road and weather conditions. In particular, the application is intended to warn drivers if they are exceeding the safe speed threshold which may result in a loss of vehicle stability and control, leading to run-off-road or roll-over events. Figure 1-4 summarizes the proposed CSW application design.



Source: Battelle

Figure 1-4. Curve Speed Warning Application Diagram

2. 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 of Minnesota (UMN)</u>

CICAS-SSA ConOps	Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA) Concept of Operations, Version 1.0 (2008)
UMN Report #1	Determination of the Alert and Warning Timing for the Cooperative Intersection Collision Avoidance System – Stop Sign Assist Using Macroscopic and Microscopic Data: CICAS-SSA, Report #1 (2010)
UMN Report #2	The Design of a Minimal Sensor Configuration for a Cooperative Intersection Collision Avoidance System – Stop Sign Assist: CICAS-SSA, Report #2 (2010)
UMN Report #3	Macroscopic Review of Driver Gap Acceptance and Rejection Behavior at Rural Thru-Stop Intersections in the US – Data Collection Results in Eight States: CICAS-SSA, Report #3 (2010)
UMN Report #4	Sign Comprehension, Considering Rotation and Location, using Random Gap Simulation for a Cooperative Intersection Collision Avoidance System – Stop Sign Assist: CICAS-SSA, Report #4 (2010)
UMN Report #5	Validation Study – On-Road Evaluation of the Cooperative Intersection Collision Avoidance System – Stop Sign Assist Sign: CICAS-SSA, Report #5 (2010)

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

MUTCD-09	Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 edition
FHWA-HOP-08-024	Traffic Signal Timing Manual
N/A	National ITS Architecture, Version 7.0
DOT HS 811 492A	Vehicle Safety Communications – Applications Final Report
TBD	Core System : System Architecture Document (SAD) – Sept. 2011

Battelle Drawings/Documents

100006441-001	Project Management Plan for Connected Vehicle Safety Concept of Operations
100006441-004	Systems Engineering Management Plan (SEMP) for Connected Vehicle Safety Concept of Operations

Society of Automotive Engineers (SAE)

J2735	Dedicated Short Range Communications (DSRC) Message Set Dictionary
J1939	Recommended Practice for a Serial Control and Communications Vehicle Network

Institute of Electrical and Electronics Engineers (IEEE)

1220-2005	IEEE Standard for Application and Management of the Systems Engineering Process
1362-1998 (R2007)	IEEE Standard for Information Technology – System Definition – Concept of Operations (ConOps) Document

3. Current System or Situation

The purpose of this document is to develop the ConOps for three safety applications that can improve safety and mobility and reduce environmental impacts over current systems by integrating infrastructure- and vehicle-based technologies and countermeasures.

The three applications of interest include:

- RLVW – Application designed to warn drivers (onboard) that they may violate an upcoming red light based on their speeds and distance to the intersection.
- SSGA – Application designed to assist drivers with vehicle gap detection on minor roads crossing major roads at stop sign-controlled intersections. In this application, vehicles traveling on the major road are not expected to stop or yield.
- CSW – Application designed to warn drivers that their current speed is too high to safely traverse an approaching curve.

Currently, warning systems are independent, meaning that the hazard detection and warnings are either completely infrastructure-based or completely vehicle-based. Integration of roadside infrastructure data (including signage and traffic signals) and vehicle data can provide a richer information set for identifying driving hazards and providing the driver with more accurate and timely warnings of unsafe conditions at an intersection. The remaining discussion within this section describes current systems and their associated functionality.

3.1 Background, Objectives, and Scope

Presently, numerous techniques and technologies, developed by both the public and private sectors, have been implemented at the roadside in an attempt to improve vehicle safety by reducing the number and severity of crashes. The success of these 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), curve warning systems, over-height or over-width detection, and more. In addition to the nearly half a million signal systems preventing crashes at intersections, there are advanced infrastructure based systems deployed that support safety improvements at both curves and at non-signalized intersections.

In addition to infrastructure elements, vehicle manufacturers, particularly in the commercial and high-end passenger vehicle market, have also 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. We document a few of these safety related solutions available on the market today.

Finally, research is being conducted in connected vehicle technologies. In one example, the CICAS program (http://www.its.dot.gov/cicas/) integrated both vehicle-based and infrastructure-based technologies to help drivers approaching an intersection understand the state of activities within the intersection. CICAS served to warn drivers about likely violations of traffic control devices (such as red-light-running) and to assist drivers in safely completing maneuvers along the roadway (like the CSW) or through cross traffic (like the Stop Sign Gap Assist). Research 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 actions can be taken to prevent an incident from occurring, or at least reduce the magnitude and impacts of the incident.

The goal of the RLVW application is to provide onboard warnings to drivers indicating that, based on their speeds and distance to the intersection; they may violate an upcoming red light.

The goal of the SSGA application is to provide approaching traffic information to support driver decisions in safely traversing stop-sign controlled intersections. The system will support stopped minor-road drivers in identifying unsafe gaps in through traffic at major road intersections.

The goal of the CSW application is to warn drivers approaching curves that their current speed is too high to safely traverse upcoming curves. This application can be based upon basic radar detection sensors that provide speed warnings or a combination of multiple types of sensors (e.g., radar and environmental sensors) that provide more sophisticated speed warnings to drivers based on roadway conditions.

3.2 Operational Policies and Constraints

Policy Influence on Safety Systems

As discussed above, the primary goal of intersection warning and CSW systems is to provide drivers with advance warnings of unsafe conditions at upcoming intersections or curves. State, regional, local, 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:

- 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 at the signalized intersection?
- Within a region, should all intersection 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 intersection warning systems or CSW?
- What guidelines are there for experimental sign and warning systems not addressed by current design standards?

Hardware and Software Considerations

The hardware and software deployed at an intersection or curve depend upon the geometry of the intersection or curve, the safety goal at that feature, its location, and the availability of power and communications. The geometry of the intersection or curve 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 curve 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 curve approach, and the software that controls the messaging and information.

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

- Types of messages that may be displayed to drivers approaching the intersection or curve
- 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.)
- 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 intersection or curve speed 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 intersection warning and CSW 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 traffic environment sensors and speed detection equipment, to determine traffic behavior such as the presence of slow or stopped traffic ahead.

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 Curve Safety

3.3.1.1 Red Light Signal Violation (CICAS-V)

Presently, no infrastructure-based red light violation applications are known to be in regular use.

3.3.1.2 Intersection Conflict Warning Systems (Stop Sign Gap Assist)

Multiple intersection conflict warning systems have been deployed throughout the country at rural, stop-controlled intersections as a means of reducing vehicle crashes and motorist fatalities. The following three installations depict examples of intersection warning systems that have been tested and are currently operational. The information presented was gathered in December 2011 as part of the FHWA ENTERPRISE project titled “Developing Consistency in ITS Safety Solutions – Intersection Conflict Warning Systems.”[2]

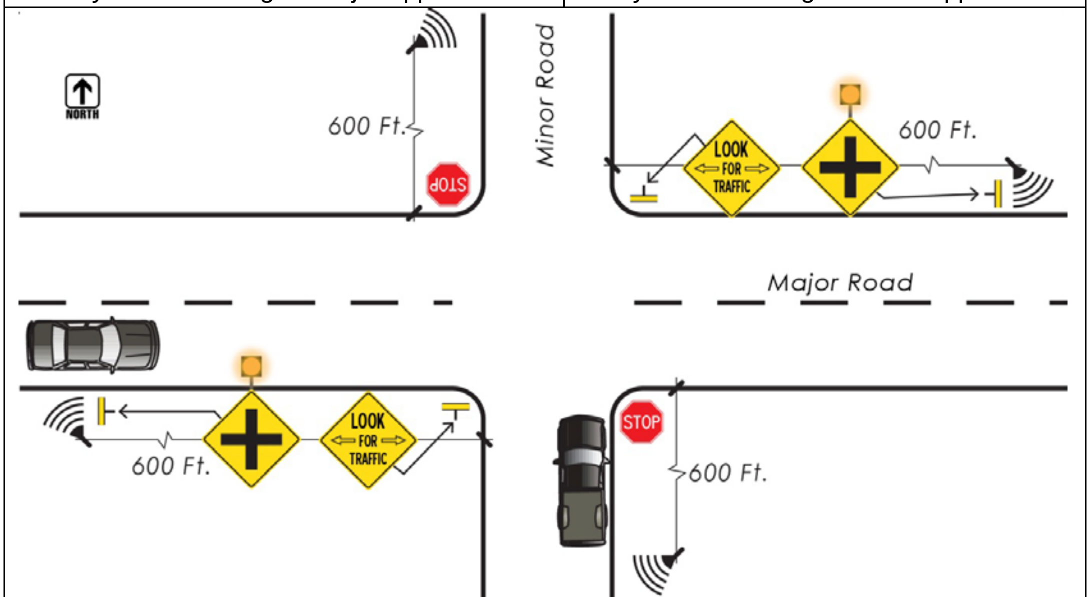
Minnesota

Multiple installations of an Intersection Conflict Warning Systems (ICWS) have been deployed at rural, 2-lane county road intersections in Minnesota that provide dynamic warnings to vehicles on the major and minor approaches. A system installed in Wright County is depicted in Figure 3-1. The signs on the major approach are placed about 600 to 800 feet in advance of the intersection. The signs on the minor approach are placed on the far-side corner from the static red STOP sign. Radar detection is used for vehicles approximately 600 feet in advance of the intersection for both directions of travel. Radar detection is also used to detect vehicles in the intersection and warn vehicles on the major approach. The results of a before-and-after evaluation of the installations in Hennepin County revealed there was a 54% reduction in traffic conflicts at the intersections, such as sudden braking, sudden acceleration or swerving.

[2] Final Design and Evaluation Guidance for Intersection Conflict Warning Systems (ICWS). December 2011. Prepared by Athey Creek Consultants. Available at: http://www.enterprise.prog.org/Projects/2010_Present/developingconsistencyIWS/Guidance%20for%20ICWS%20Version%201-122011.pdf

Dynamic Warning on Major Approach

Dynamic Warning on Minor Approach



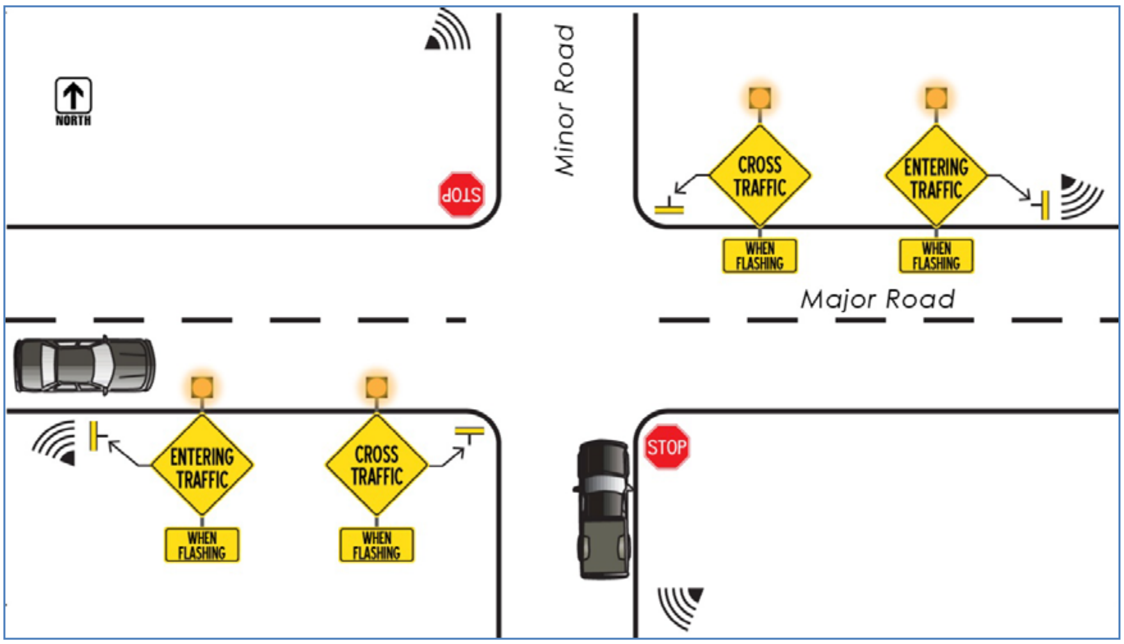
Intersection Overview

Source: (Top) ENTERPRISE Pooled Fund Study “Design and Evaluation Guidance for Intersection Conflict Warning Systems (ICWS) Version 1: December 2011”
Source: (Bottom) URS

Figure 3-1. Minnesota Rural ICWS Installations

Based on the success of these types of ICWS installations, the Minnesota Department of Transportation (Mn/DOT) is planning to move forward with a more widespread deployment of ICWS at up to 100 rural, stop-controlled intersections throughout Minnesota. These systems typically consist of a combination of static signs, vehicle detection equipment and flashing beacons, as illustrated in Figure 3-2. As the vehicle on the major road approaches the intersection, it is detected and a dynamic warning is activated for the vehicle on the minor road at the stop sign. Conversely, vehicles on the major road are also dynamically warned of vehicles entering an intersection from the minor road. While the system concept and design are similar to the system illustrated in Figure 3-1, the static and dynamic elements of the ICWS have been slightly modified.

Mn/DOT has applied for FY 2012 TIGER Discretionary Grants to provide funding for the widespread deployment of ICWS at 100 intersections throughout Minnesota. Based on the amount of funding received, Mn/DOT will deploy ICWS at 32 high-risk intersections first, followed by 39 medium-risk intersections, and then 29 low-risk intersections.



Source: URS

Figure 3-2. Future Minnesota Rural ICWS Installation Diagram

Missouri

ICWS have been installed in Missouri at a total of 9 sites where a 2-lane major arterial intersects a 2-lane minor road. Figure 3-3 depicts one installation of an ICWS in the community of Tunas within Dallas County, at a rural, 2-lane county road intersection of State Highway 73 and Routes E/D. This system provides dynamic warnings to vehicles on the major approach of the intersection. The signs are placed about 600 to 800 feet in advance of the intersection. Loop detection is used to detect vehicles entering the intersection from the minor approach, which provides the dynamic warning to the sign on the major approach. The results of a before-and-after study revealed there was a 28% reduction in all crashes at the 9 sites with a warning message presented to drivers on the major arterial road.

Source: (Top) ENTERPRISE Pooled Fund Study "Design and Evaluation Guidance for Intersection Conflict Warning Systems (ICWS) Version 1: December 2011"
Source: (Bottom) URS

Dynamic Warning on Major Approach

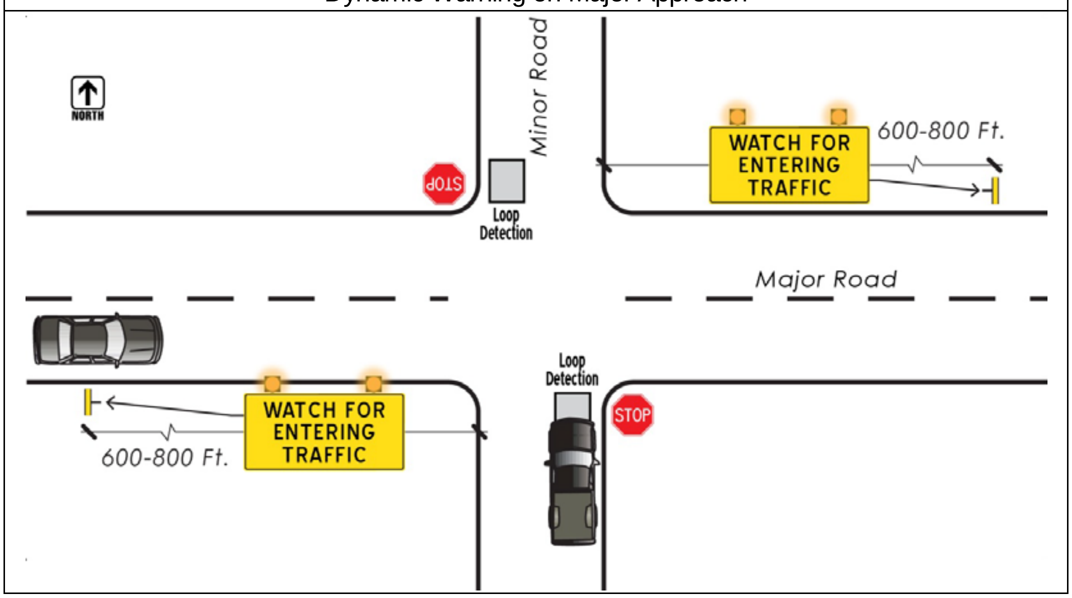


Figure 3-3. Dallas County, Missouri Rural ICWS Installation

North Carolina

ICWS have been installed in North Carolina at 4 sites where a 2-lane major arterial intersects a 2-lane minor road, and an additional 7 sites where a 4-lane major arterial intersects a 2-lane minor road. Figure 3-4 depicts one installation of an ICWS in Pender County, at a rural, 4-lane county road intersection of US 421 with State Highway 210. This system provides dynamic warnings to vehicles on the major approach through static/dynamic signs placed about 1,000 feet in advance of the intersection. Loop detection is used to detect vehicles entering the intersection from the minor approach, which provides the dynamic warning to the sign on the major approach. The results of a simple before-and-after study revealed there was a 46% reduction in crashes at the 4 sites where a 2-lane major arterial intersects a 2-lane minor road, and a nearly 20% reduction in crashes at the 7 sites where a 4-lane major arterial intersects a 2-lane minor road.

Source: (Top) ENTERPRISE Pooled Fund Study "Design and Evaluation Guidance for Intersection Conflict Warning Systems (ICWS) Version 1: December 2011"
Source: (Bottom) URS

Dynamic Warning on Major Approach

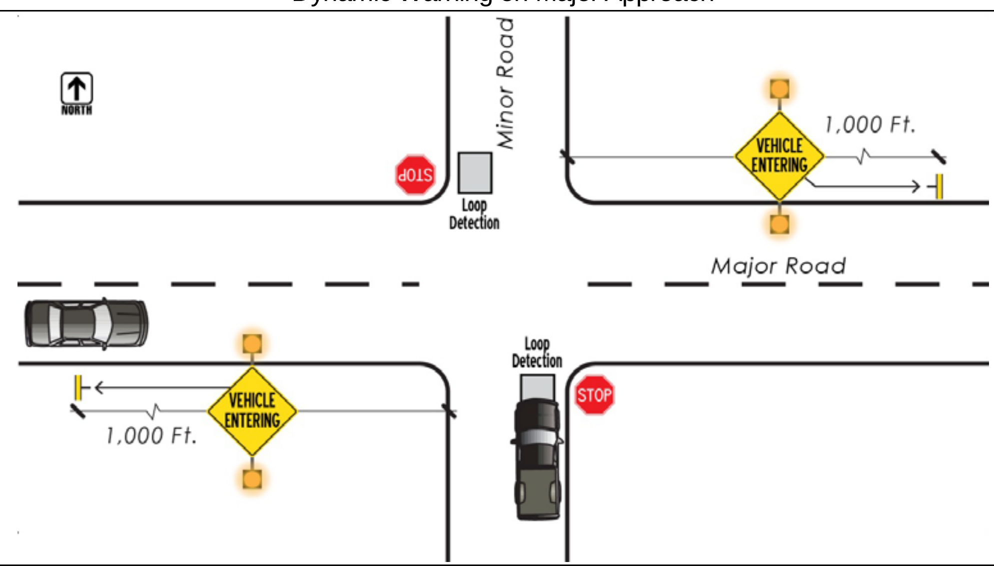


Figure 3-4. Pender County, North Carolina Rural ICWS Installation

3.3.1.3 Curve Speed Warning

Multiple installations of CSW systems have been deployed throughout the country as a means of reducing vehicle crashes resulting in motorist fatalities. The following three installations depict examples of CSW systems that have been tested and are currently operational.

<u>Detroit, Michigan, Metro Area</u>

Two curve warning systems have been installed for the Michigan DOT Metro Region in the Detroit area at the following locations:

1. Along I-75 north and south of Exit 60 (Nine Mile Road) in Hazel Park. The systems are installed at an “S” curve that has seen numerous crashes
2. On the Northbound I-75 Ramp at Exit 51 from I-375 in Detroit. This system is for a two lane connector where I-75 turns to head north out of downtown Detroit.

Figure 3-5 depicts an overview of the system along I-75 and the components that provide warnings to vehicles. The system incorporates the data from:

1. Radar speed detectors installed prior to the curve
2. Roadway surface sensors installed to detect surface moisture and temperature
3. Visibility sensors that detect the level of visibility in the area
4. Vehicle detection sensors to detect traffic congestion on the curve.

These detectors and sensors feed a system processor that determines the appropriate message to display on a 3-line DMS to motorists approaching the curves. Varying messages can appear on the DMS to warn motorists of unsafe approach speeds based on either on the environmental conditions – “SNOWY CONDITIONS / CURVE AHEAD / REDUCE SPEED” -- or the presence of congestion along the curve -- “STOPPED TRAFFIC / AHEAD / REDUCE SPEED”. Further information on the warning messages displayed to drivers is presented in Section 3.4.

Anticipated benefits to be realized by the Michigan DOT Metro Region include improved motorist safety, a reduction in crashes and resulting traffic congestion in the project area, and a measurable system performance to support a benefit-cost ratio assessment of the system over time. As of the writing of this report, a formal system evaluation has not been completed to quantify the extent of these anticipated benefits.

Source: Michigan DOT and URS

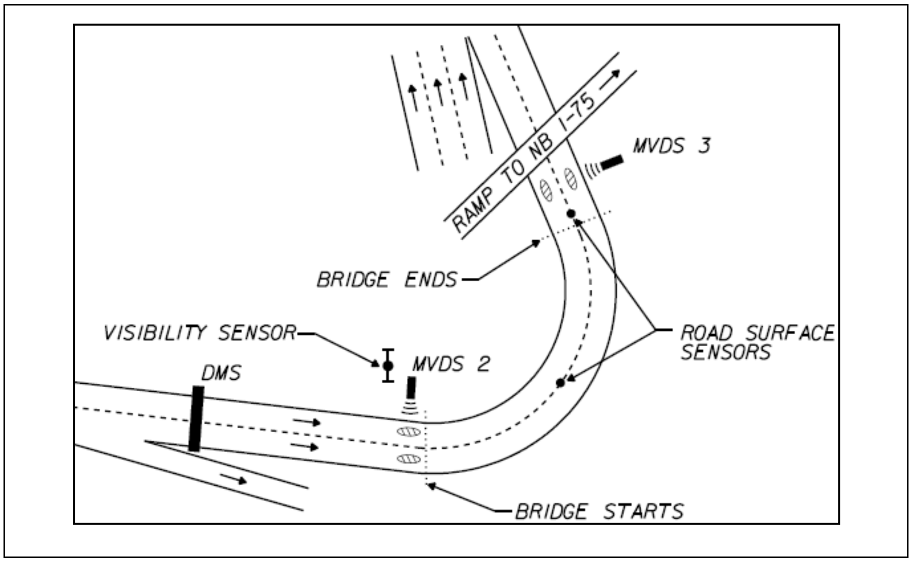


Figure 3-5. CSW System Installation Overview in Detroit, Michigan

Tallulah Falls, Georgia

One curve warning system has been developed and installed by the Georgia DOT in the northern area of the State to warn truck drivers along US 441 approaching a curve from both directions of travel. The system incorporates data from:

1. Radar speed detectors installed prior to the curve
2. Vehicle height detection sensors to detect commercial vehicle truck traffic approaching the curve.

If a commercial vehicle above a certain height threshold is detected traveling above a safe speed, the system will display a message on a DMS prior to the curve, warning drivers to slow down. Figure 3-6 depicts an overview of the system and the components that provide warnings to vehicles. As of the writing of this report, a formal system evaluation has not been completed to document any observed benefits with regard to this type of system. Further information on the warning messages displayed to drivers is presented in Section 3.4 of this document.

Source: Michigan DOT and URS

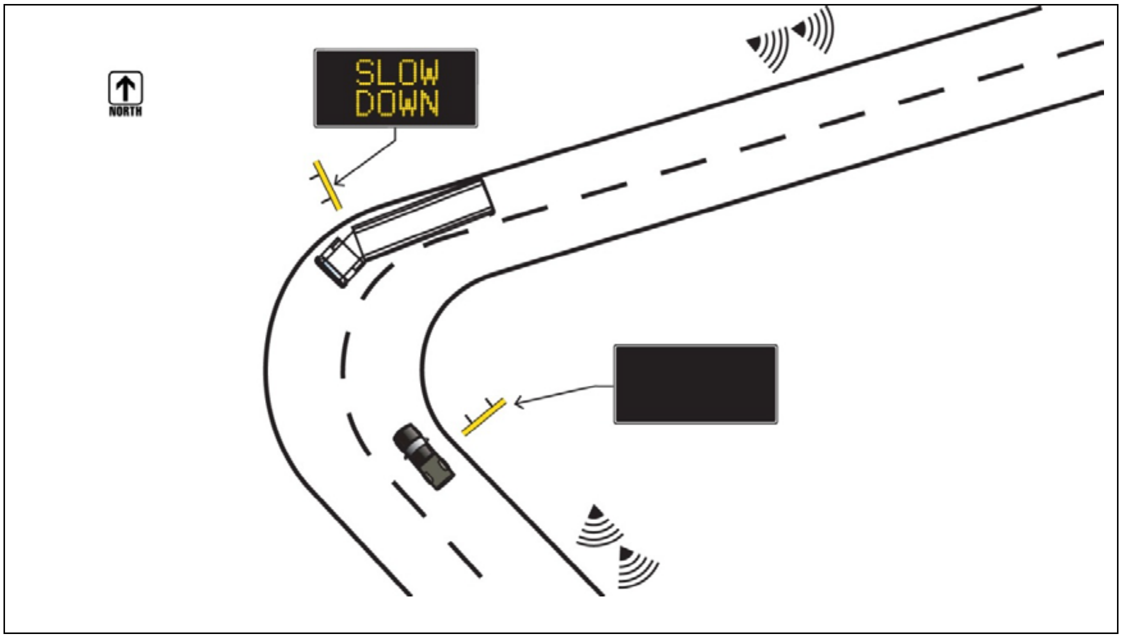


Figure 3-6. Curve Warning System Installation Overview in Tallulah Falls, GA

Myrtle Creek, Oregon

One CSW was deployed on the I-5 in Myrtle Creek that uses radar detectors to measure the speeds of approaching traffic and warn motorists driving too fast to reduce their speeds. Doppler technology radars also measure travel direction, which is important for filtering vehicles traveling in the opposite direction. A nearby sign controller unit and computer software program is used to manage the speed inputs and (locally) modify the message on the 3-line DMS. Figure 3-7 below displays a visual of the DMS installed next to static signs that previously had warned drivers of unsafe speeds.[3] Further information on the warning messages displayed to drivers is presented in Section 3.4.

An evaluation of the system found that it was effective in reducing the mean speeds of passenger cars and trucks by approximately 3 mph for the southbound direction and 2 mph for the northbound direction. In addition, public intercept surveys of motorists at nearby rest areas revealed a positive perception of the system.

[3] Field Evaluation of the Myrtle Creek Advanced Curve Warning System. FHWA-OR-RD-06-13. Written by: Robert L. Bertini, Christopher M. Monsere, Casey Nolan, Peter Bosa, and Tarek Abou El-Seoud, June 2006.

Aerial Overview of I-5 at Myrtle Creek, OR

Northbound I-5 Before System installation

Northbound I-5 After System installation

Southbound I-5 Before System installation

Southbound I-5 After System installation

FHWA's "Field Evaluation of the Myrtle Creek Advanced Curve Warning System." FHWA-OR-RD-06-13.

Figure 3-7. CSW System Installation in Myrtle Creek, Oregon

3.3.2 Current Infrastructure-Based Technologies Supporting Safety Applications

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

- Traffic Signal Controllers
- Road Weather Information Systems / Environmental Sensor Systems
- Speed Detection
- Vehicle Classification Systems
- Driver-Infrastructure Interfaces

Each of these technologies are discussed in greater detail below.

3.3.2.1 Traffic Signal Controllers

A traffic signal controller (TSC) is a type of traffic control device that manages access of conflicting pathways of travel for different classes of users at an intersection. Housed in a controller cabinet along with supporting hardware, the TSC senses the presence of vehicles in conflicting traffic movements through its interface with the input module(s). These modules typically consist of vehicle/pedestrian detection sensors installed at locations at an intersection, and for certain classes of users; input modules may also exist to allow for signal timing pre-emption or prioritization service request. The TSC manages these input requests and provides green time to traffic movements by changing the signal indication (green/yellow/red) for the respective movements as established at the output modules. The output module(s), which consist of a set of load switches, in turn provide the signal indications that are displayed to the travelers via the signal heads at an intersection. A conflict monitoring unit, also known as a malfunction management unit, serves as a safety system, ensuring that no two conflicting phases are active at the same time.

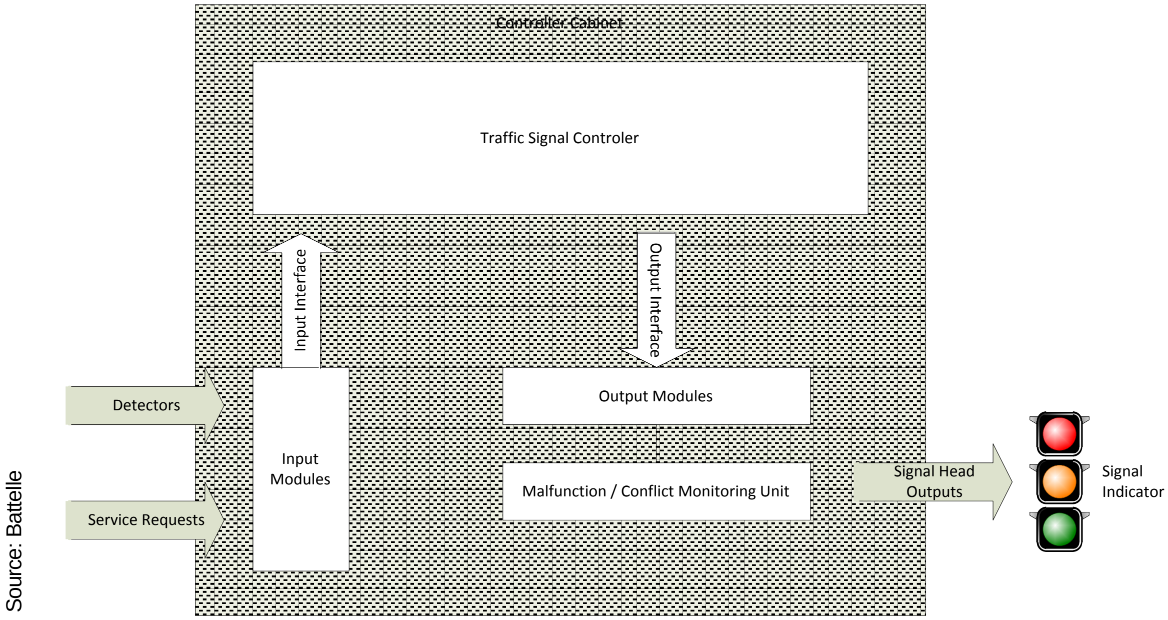


Figure 3-8. Typical Signal Control System

Currently five major types of computer-controlled traffic signal controllers are in use throughout the country. A large portion of these implement the functionality specified by one of many varying standards, as identified below. These controllers can be thought of in two different families: those under the auspices of National Electronics Manufacturers Association (NEMA) and those whose evolution followed the 170/2070/ATC path. The types of controllers include:

- NEMA TS1 Traffic Signal Controller
- NEMA TS2
  - Type 1 Traffic Signal Controller
  - Type 2 Traffic Signal Controller
- Type-170 Traffic Signal Controller
- 2070 Type Signal Controller
- Advanced Traffic Signal Controller (ATC).

The NEMA TS1[4] was the first controller specification produced by NEMA. This specification defined a functional and electrical interface for the controller and was one of the earliest to provide actuated control for a single intersection. NEMA TS2 followed in the 1980s and included specifications for the controller unit, a malfunction management unit, terminals and facilities, detectors, load switches, flashers, and cabinets. It also included the addition of serial communication using a synchronous data link control (SDLC) port. The TS2 Type 2 maintains the same interface as the TS1 and can be used in a TS1 cabinet, whereas the TS2 forgoes the original interfaces in favor of the serial bus.

[4] http://ops.fhwa.dot.gov/arterial_mgmt/rpt/sig_tim_proc/sect_3.htm. Accessed 05-18-2012.

The Model 170 was developed by the States of California and New York around the same time the NEMA standards were developed. This specification standardized the hardware instead of the functionality of the controller in order to make the controller modules interchangeable between different manufacturers. The standard specifies the controller, cabinet, and all required accessories including sensors. In addition, with the implementation of various software packages, the Model 170 can be used for other traffic control purposes, such as ramp metering control and changeable lane control. Although this standard defined a major hardware advance, there was no significant change in the controller timing operation relative to the TS1. The Model 2070 was then developed to attain national consensus and is the first in a family of open-architecture ATC controllers (ITE ATC Type 2070[5]).

Finally, the ITE Advanced Transportation Controller (ATC) specifies the second in a family of open-architecture ATC controllers. This standard defines a single-board computer ("engine board") that provides a standard physical and electrical interface to a "host module." The ATC host module is required to be configurable to support either NEMA-style or 170/ITS-style cabinets, and is compatible with all Type 2070 cabinet communication standards. The ATC is also required to provide a straightforward software portability path for software designed to operate on the Type 2070 controller.

Regardless of the standard used to specify the controller, the basic functions of all TSCs are similar, and as such, are a critical source of information for future connected vehicle safety applications. Present systems do not currently provide the SPaT messages needed by these applications. However, it is possible to satisfy these needs by extending the current message set standards to support these additional data flows and interfaces, and to also either directly update the controller firmware, or to instrument the signal cabinet with other processing equipment to generate, receive, and process these new messages. According to a recent study performed by the ATC Joint Committee, released in March 2011, approximately 157,000 of the 307,000 currently deployed controllers have the capability to provide this SPaT information to external entities. This information is crucial to any signal-related safety applications.

3.3.2.2 Road Weather Information Systems / Environmental Sensor Systems

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. Table 3-1 provides statistics from the 2010 FHWA ITS Deployment Tracking Survey on the number of traffic management agencies that have deployed types of environmental sensors along freeways and arterials.[6] The statistics indicate that operational sensors and environmental sensor systems/stations (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.

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[5] http://www.standards.its.dot.gov/fact_sheet.asp?f=14. Accessed 05-18-2012.

[6] 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

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

	Freeway	Arterial
In-pavement sensors		
Agencies deploying in-pavement sensors to detect the condition of the pavement	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

3.3.2.3 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.[7] 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.

[7] 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

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

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

3.3.2.4 Vehicle Classification Systems

Vehicle classification systems utilize basic roadside detectors to measure vehicles that exceed a certain height threshold and whether or not they may impact bridges with low 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 over-height warning system.[8]

3.3.2.5 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 6 States had deployed ICWS that used sensors to monitor traffic approaching dangerous intersections and then activate flashers to warn vehicles of approaching cross traffic.[9]

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[8] 2010 FHWA ITS Deployment Tracking Survey. Available at: http://www.itsdeployment.its.dot.gov/FM.aspx

[9] 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

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, 8 States had similar systems to warn drivers approaching curves on highways, and 7 States had similar systems to warn drivers approaching downhill roadway grades.[10]

As of 2010, 27 traffic management agencies reported using Dynamic Curve Warning Systems among their freeway incident management strategies.[11]

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.

3.3.3 Current Vehicle-Based Approach for Intersection and Curve Safety

In addition to the infrastructure-based systems identified above, considerable research and development has been conducted on multiple vehicle-based crash warning systems including collision warning, rollover, and/or lane departure components. Some of these technologies are commercially available, particularly on trucks. These crash warning systems are based entirely on onboard vehicle sensors to identify potential hazards and warn the driver. These systems do not rely on any roadside infrastructure systems to identify threats.

3.3.3.1 Rollover Prevention Systems

A major safety concern for commercial vehicles is the potential for rollover events. Rollover events are likely to occur when a truck is conducting avoidance maneuvers or turning. Several factors play into this danger, including excessive speed around curves. Currently, several manufacturers offer commercial vehicle stability systems. These systems prevent rollovers by automatically applying a truck's brakes to slow the vehicle down when the system identifies the critical rollover risk threshold is reached.

Bendix® ABS-6 Advanced with ESP® Stability System brochure.

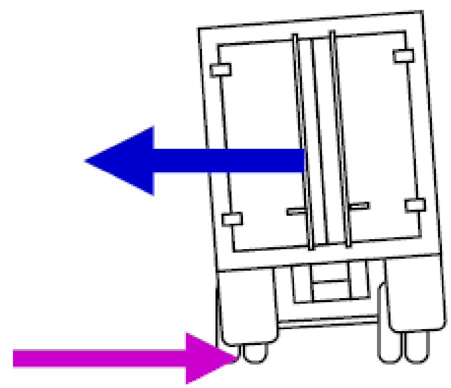

Figure 3-9. Instability Potentially Resulting in Rollover

[10] 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

[11] 2010 FHWA ITS Deployment Tracking Survey. Available at: http://www.itsdeployment.its.dot.gov/FM.aspx

Stability systems utilize "roll stability" to help counteract the potential for a rollover event while a truck is changing direction. Instability is likely to occur when the lateral acceleration (generated due to the change in direction) creates a force that begins to push the truck horizontally while the friction between the tires and the road opposes the force. If the lateral force is high enough, one side of the vehicle may begin to lift off the ground. This lift may lead to a rollover as shown in Figure 3-9.[12]

Bendix® ABS-6 Advanced with ESP® Stability System brochure.

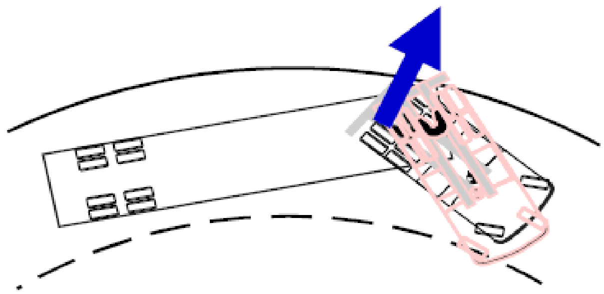

Figure 3-10. Instability Potentially Resulting in Over-Steer Situation

Stability systems may also utilize yaw stability to help counteract over-steer and under-steer situations that may lead to jacknife. In this case, instability occurs when the friction between the road and the tires is not sufficient to oppose the lateral force of the truck. This may lead to one or more tires sliding and result in the truck spinning. The spinning is caused by either an under-steer situation (steer axle tires slide) or an over-steer situation (rear axle tires slide).[13] Either one may result in jackknife of a combination tractor-trailer.

The following are examples of currently available vehicle-based systems to prevent these events from occurring in commercial vehicles:

- Bendix® ESP® System: A truck stability system that recognizes and assists in under-steer and over-steer loss-of-control driving events and loss of traction situations.[14] The system uses wheel speed, lateral acceleration, yaw, and steering angle sensors to detect the vehicle's movement. If the vehicle either (1) shows a tendency to leave its travel path or (2) approaches a critical threshold value, the system will intervene to assist the driver. In the case of a potential rollover event the system overrides the throttle and applies brake pressure at the selected wheel ends to slow the vehicle below a critical threshold. In the case of a vehicle slide (over-steer or under-steer situation) the system will reduce the throttle and brake one or more of the four corners of the vehicle to better align the vehicle with an appropriate travel path.[15]
- Meritor WABCO SmartTrac™ Stability Control System: A vehicle safety system that includes roll stability and directional stability control. The system minimizes rollover risks by automatically intervening and assisting the driver when risk is detected. The system works by continuously checking the truck's lateral acceleration and compares it to a critical threshold where rollover may occur. When the threshold is exceeded, the system intervenes by reducing engine torque and engaging the engine retarder, while automatically applying the drive axle and trailer brakes.[16]

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[12] http://www.bendix.com/media/documents/products_1/absstability/truckstractors/StabilityFAQ.pdf

[13] http://www.bendix.com/media/documents/products_1/absstability/truckstractors/StabilityFAQ.pdf

[14] http://www.bendix.com/en/products/absstability/absstability_1.jsp

[15] http://www.bendix.com/media/documents/products_1/absstability/truckstractors/StabilityFAQ.pdf

[16] http://www.meritorwabco.com/MeritorWABCO_document/SP1079.pdf

- Haldex Trailer Rollover Stability System: A trailer-based control system that constantly monitors the truck's movements. To reduce the risk of rollover, the system uses adaptive learning loop technology to calculate the truck's lateral acceleration, vehicle speed, air suspension, and air system pressure 100 times per second. When the system senses that a rollover is imminent, it automatically brakes the truck to slow and stabilize it.[17]

3.3.3.2 Lane Departure (Run-Off-Road) Warning Systems

Another major safety concern for all vehicle classes is unintended lane departures. Trucks are known to occasionally veer outside their lane and cross the lane markers. While this normal lane departure scenario is not necessarily a speed management issue, some of the technology associated with lane departure warning systems may find application in CSW applications. Lane departures, which can occur for a variety of reasons including distracted driving, inattention, or sleepiness, may lead to run-off-road (ROR) incidents. These incidents could result in property damage, injuries, or fatalities. According to research conducted by AAHSTO, in 2006, 58 percent of total automotive-based fatalities were related to lane departures.[18]

There are several commercially available vehicle-based warning systems to address such situations. These systems include:

- AutoVue® Lane Departure Warning System: A vision-based lane system that alerts drivers who inadvertently drift out of their lane. The system includes a camera, onboard computer, and image processing algorithms. The camera tracks the visible lane markings and the system algorithms detect when the vehicle begins to drift toward an unintended lane change. If this change occurs, the system automatically emits a distinctive rumble strip or other audible warning sound, alerting the driver to make a correction.[19] The system is available as an OEM option in passenger cars and as an aftermarket option on heavy trucks.[20]
- Takata's SafeTraK (includes Lane Departure Warning System): This commercial vehicle vision-based system monitors the road ahead and audibly warns drivers of unintentional road departures.[21] The system alerts drivers to weaving, lane drifts, or lane changes that occur without a turn signal application. The system works by detecting and classifying lane markers on the road via a compact unit composed of a camera, optics, processor, and a power supply. The system calibrates itself and can be installed directly on a vehicle's windshield.[22] SafeTraK also includes forward collision warning and driver alertness warning features.
- Mobileeye Lane Departure Warning: A passenger vehicle lane departure system that recognizes lane markings and road edges and estimates the position of the car within the lane. Using a lane crossing calculation, the system provides the driver a warning in case of unintentional lane departure. The warning mechanism is flexible: the system can be set to

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[17] http://www.haldex.com/Documents/hbsna/ABS/L20578W_TRS_Brochure_6-10.pdf

[18] http://www.iteris.com/press.aspx?q=99

[19] http://www.bendix.com/media/documents/press_releases/2011/bendixcompletespurchaseofvehiclesensorbusinessfromiterisinc.pdf

[20] http://www.iteris.com/press.aspx?q=99

[21] http://www.takata.com/en/products/electronics02.html#02

[22] http://www.4-traders.com/MERITOR-INC-11684/news/MERITOR-INC-Meritor-WABCO-to-Offer-SafeTraK-Takata-s-Lane-Departure-Warning-System-in-North-Ameri-14028334/

warn only when the vehicle is actually crossing the lane marking, or give an early warning, before lane markings are crossed. The warning can also be adapted to the type of road (e.g., it can provide the driver with more slack in case of narrow roads or allow the driver to "cut" curves.)[23]

3.3.3.3 Intersection Safety

Presently there are no widely adopted onboard safety applications which address intersection safety.

3.3.4 Current Vehicle-Based Technologies Supporting Safety Applications

The system identified in Section 3.3.3 depend 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 systems identified in Section 3.3.3 depend on many different onboard technologies that are used either singularly or in combination with other technologies to support 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 telematic 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 is non-proprietary. The emissions related data source is referred to as the On Board Data II (OBD2) standard.[24] OBD2 operates over a standardized connector (SAE J1962), using one of five interface standards including IS0 15765, ISO 14320, ISO9141-2, 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 is available pertains 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:

[23] http://www.mobileye.com/technology/applications/lane-detection/lane-departure-warning/

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

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

All modern cars have at least one controller area network (CAN) bus that interconnects all major electronic control units (ECUs) in the vehicle. The CAN bus data is proprietary to the manufacturer, but 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, light status
- Brake actuation and 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 and 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 information 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 is generally proprietary to a fleet because it pertains to competitive logistical efficiencies that freight operators have developed. Vehicle tracking location data is 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 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 system, a brief discussion of the modes of operation are included below.

3.4.1 Intersection Warning Systems (CICAS-Stop Sign Assist)

The three types of intersection conflict warning systems described in Section 3.3.1.2 all include the use of static warning signs with dynamic flashers, and all the systems have two basic modes of operation: 1) a default mode in which the dynamic flashers are not active and are not providing a dynamic warning to drivers, and 2) an active mode in which the flashers are activated and flash when vehicles are detected within or approaching the intersection.

3.4.2 Curve Speed Warning (CSW) Systems

There are two general modes of operation for CSW Systems that include: 1) a default mode that provides drivers with a static warning of the curve and 2) an active mode that warns drivers when their travel speeds exceed safety thresholds for current conditions. The message provided to drivers can vary based on the available data and complexity of the algorithm used to assess safe speed thresholds. The modes of operation for the three CSW systems discussed earlier are summarized below.

Detroit, Michigan Metro Area

The default mode of operation for the 3-line DMS presents the message “CURVE AHEAD / 50 MPH” for all vehicles traveling between 20 MPH and 75 MPH. The third line of the DMS will flash “***SLOW DOWN***” if vehicle speeds above 75 MPH are detected.

The active mode of operation can provide different messages on the DMS based on the speeds detected and on other information gathered from roadway and environmental sensors. Messages can read “SNOWY CONDITIONS / CURVE AHEAD / REDUCE SPEED” for conditions in which snow is falling in the area. The presence of slow moving vehicles along the curve can trigger the message “SLOW TRAFFIC / AHEAD / REDUCE SPEED.” The presence of stopped vehicles along the curve can trigger the message “STOPPED TRAFFIC / AHEAD / REDUCE SPEED.” If poor visibility is detected from nearby environmental conditions, the message will display “POOR VISIBILITY / CURVE AHEAD / USE CAUTION.” These messages are activated when vehicles are detected traveling between 20 and 75 MPH on the roadway.

During the active mode, for all vehicles detected to be traveling greater than 75 MPH approaching the curve, the third line of the DMS will flash the text “***SLOW DOWN***” to warn drivers of their excessive speed.

A manual mode of operation for the 3-line DMS can read “STOPPED TRAFFIC / AHEAD / REDUCE SPEED” with an operator providing the override message directly to the DMS.

Figure 3-11 on the following page displays the general decision process involved with this system and the messages that are displayed on the DMS based on speed, vehicle, and environmental measures.

Tallulah Falls, Georgia

The default mode of operation for the curve warning system developed for this area is to provide no warning message on the DMS to trucks and other vehicles approaching the curve area of the roadway.

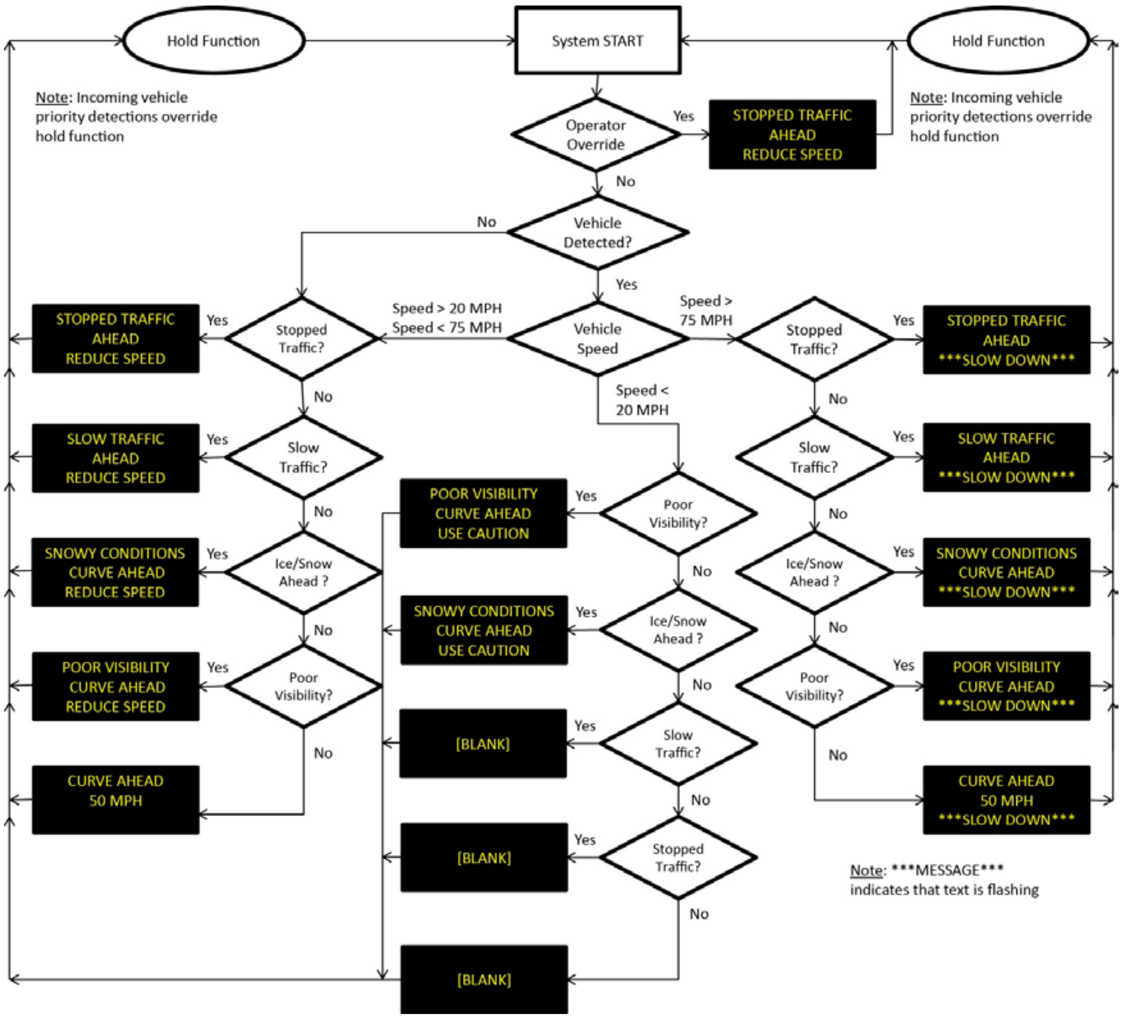
The active mode of operation is triggered when vehicles exceeding the specified height and traveling above a safe speed are detected. The DMS will display a message prior to the curve, warning drivers to slow down that reads “SLOW DOWN / TRUCKS.”

Myrtle Creek, Oregon

The default mode of operation for this system provides a message that appears on the 3-line DMS for all vehicles traveling below 50 MPH that flashes between “CAUTION” and “SHARP / CURVES / AHEAD” at 2-second intervals.

An active mode of operation exists for vehicles traveling between 50 and 70 MPH, in which the DMS will flash two messages at 2-second intervals **--** “SLOW / DOWN” and “YOUR / SPEED IS / XX MPH” **--** to alert the driver to slow down.

For vehicles traveling over 70 MPH, the DMS will flash two messages at 2-second intervals **--** “SLOW / DOWN” and “YOUR / SPEED IS / OVER 70 MPH” **--** to alert the driver to slow down.



Source: Michigan DOT and URS

Figure 3-11. Detroit, MI Curve Warning System Messages Displayed Based on Speed, Vehicle, and Environmental Measures

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.

Non-Motorized Users

Non-motorized users, which includes both pedestrians and bicyclists, are a safety consideration at intersections, both signalized and non-signalized. These users have different operating characteristics and requirements than 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 exist that 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 not a direct user of the ITS information, the need to satisfy the concerns and requests of these groups can greatly influence the design and manner in which ITS technologies operate in any particular region.

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. Justification for and Nature of Changes

Connected Vehicle applications offer tremendous promise for major improvements in highway safety and mobility, and for reducing the environmental impact of highway travel. 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 (slippery road surface condition, for example) with data from the vehicle (such as speed in a curve) to assess likelihood of crash (run-off-road, 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 30,000 to 40,000 fatalities experienced each year on our roads and highways.

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 three high-priority 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 just over 30,000 fatal crashes in the United States, making traffic-related incidents the most significant cause of preventable deaths in this country. 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 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 information 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 unequipped 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.

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 four sets of user needs, one set common to all three identified safety applications (CSW, SSGA, RLVW) 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

The following list of user needs has been identified as being common to all three applications documented in this ConOps.

Table 4-1. Common User Needs

No.	Title	Description
UN-COM-001	Range of 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 Vehicles	(Mandatory) The application needs to work in and with all existing infrastructure and with all vehicle classes and types affected by the application.
UN-COM-003	Environmental Conditions	(Mandatory) The application needs to perform effectively in all weather, road surface, and visibility conditions.
UN-COM-004	Performance Location	(Mandatory) The application needs to perform effectively in urban, suburban, sub-rural, and rural areas.
UN-COM-005	Vehicle Position Accuracy	(Mandatory) The application's positioning system needs to be accurate enough to create alerts and/or warnings when warranted and to avoid false positive alerts and/or warnings.
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 positive alerts and/or warnings and false negative decision errors.
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.
UN-COM-009	Self-Diagnostics	(Mandatory) The application needs to provide continuous diagnostic self-testing including both onboard and infrastructure self-diagnostic tools, allowing a default fail safe mode for any driver interface when critical components are off-line. This includes an indication to the driver that onboard components are offline.
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.

No.	Title	Description
UN-COM-011	DELETED	DELETED
UN-COM-012	DELETED	DELETED
UN-COM-013	DELETED	DELETED
UN-COM-014	Integrity of the System	(Mandatory) The application components need to minimize unauthorized physical access.
UN-COM-015	Notification of Invasion	(Mandatory) The application should allow respective owners/operators of the vehicle or infrastructure components to know that unauthorized 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	System Security Performance	(Mandatory) The application message authentication needs to be fast enough to support the objectives of the safety application.
UN-COM-018	System upgrades	(Mandatory) Application system 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) The application needs to perform effectively 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	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 System.	V2I safety application alerts and/or warnings shall only be issued when real-time conditions are determined to warrant an alert or warning.

4.2.2 User Needs Associated with the Red Light Violation Warning App

Table 4-2 shows user needs specifically for a RLVW application and are in addition to the common user needs identified in Table 4-1.

Table 4-2. Red Light Violation Warning User Needs

No.	Title	Description
UN-RLV-001	Application Function	(Mandatory) The RLVW Application needs to work at all signalized intersections, including grade rail crossings.
UN-RLV-002	Signal Phase and Timing	(Mandatory) The RLVW Application needs to know the current SPaT information from the traffic signal controller at a signalized intersection.
UN-RLV-003	Onboard Notification	(Mandatory) The RLVW Application needs to warn potential violators of signal control status in time for the driver to take appropriate action.
UN-RLV-004	Intersection Geometry	(Mandatory) The RLVW Application needs to function for all intersection geometries.
UN-RLV-005	Intersection Data Needs	(Mandatory) The RLVW Application needs intersection geometry information.
UN-RLV-006	DELETED	DELETED
UN-RLV-007	DELETED	DELETED
UN-RLV-008	DELETED	DELETED
UN-RLV-009	Common Time Source	(Mandatory) All equipped systems involved in the RLVW application, including both onboard and infrastructure elements, need to have a common time source.

4.2.3 User Needs Associated with the Stop Sign Gap Assist Application

Table 4-3 shows user needs specifically for a SSGA application and are in addition to the common user needs identified in Table 4-1.

Table 4-3. Stop Sign Gap Assist User Needs

No.	Title	Description
UN-SSGA-001	Major Road Disruption	(Mandatory) The SSGA application needs to avoid impeding traffic on the major road.
UN-SSGA-002	Additional Signage/Clutter	(Mandatory) The SSGA Application needs minimal additional signage and needs to not interfere with existing traffic control devices.
UN-SSGA-003	Application Timing	(Mandatory) The SSGA Application needs to alert minor road drivers of oncoming major road traffic in time for them to avoid entering the intersection.
UN-SSGA-004	Requirements for Median Application	(Optional) The SSGA Application needs to monitor the median (if applicable) for occupancy and accommodate major road traffic that exists at the minor road.
UN-SSGA-005	Reference Frame	(Mandatory) The SSGA Application needs to use a prohibitive frame, which indicates a condition that may be unsafe.
UN-SSGA-006	Intersection Type	(Mandatory) The SSGA Application needs to work at all stop-sign controlled intersections.
UN-SSGA-007	Intersection Geometry	(Mandatory) The SSGA Application needs to perform for a wide range of intersection geometries.
UN-SSGA-008	Intersection Data Needs	(Mandatory) The SSGA Application needs information regarding the intersection geometry.
UN-SSGA-009	Failure Mode	(Mandatory) The SSGA Application needs to have a failure mode that restores the intersection to default, static, regulatory signing already in place.
UN-SSGA-010	Common Time Source	(Mandatory) All equipped systems involved in the SSGA application, including both onboard and infrastructure elements, need to have a common time source.

4.2.4 User Needs Associated with the Curve Speed Warning Application

Table 4-4 shows user needs specifically for a CSW application and are in addition to the common user needs identified in Table 4-1.

Table 4-4. Curve Speed Warning User Needs

No.	Title	Description
UN-CSW-001	Road Geometry Data Needs	(Mandatory) CSW needs information regarding roadway geometry.
UN-CSW-002	Road and Weather Condition Data Needs	(Optional) CSW needs information regarding weather and road conditions.
UN-CSW-003	Vehicle Based Data Needs	(Mandatory) CSW needs dynamic vehicle telematics data and vehicle configuration data.
UN-CSW-004	Application Functionality By Road and Curve Characteristics	(Mandatory) CSW needs to function for all road types, including roads in which the curve is the only possible path and roads that diverge into different paths in which the driver selects the curved pathway.
UN-CSW-005	Application Capabilities	(Mandatory) CSW needs to determine whether the driver is taking a curve when driving on a roadway that diverges into different paths, in which the driver selects the curved pathway.
UN-CSW-006	Speed Calculation	(Mandatory) CSW needs to calculate an appropriate speed to navigate the curve given a set of data elements: road geometry, environmental road conditions, vehicle configuration data, and available telematics. Any unavailable data will be given a previously determined default value in order to compute speed.
UN-CSW-007	DELETED	DELETED
UN-CSW-008	Vehicle Notification Timing	(Mandatory) CSW needs to, as appropriate, alert or warn the driver in a timely manner to reduce speed in order to safely negotiate the curve.
UN-CSW-009	Other Vehicle Influences	(Optional) CSW application needs to factor in available V2V information to calculate an appropriate speed.
UN-CSW-010	Moved to COMMON	Moved to COMMON

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 three applications identified herein as high-priority, and as such, they are the focus of this document. No specific prioritization between these applications has been made, nor has any unique distinction as mandatory or optional been made amongst the user needs.

4.4 Changes Considered but not Included

The approach used in articulating the ConOps for all three 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.

Scenarios have been developed, particularly for the SSGA application where either V2V communications between approaching and stopped vehicles or advanced V2I communications from approaching vehicle to the infrastructure, and then to the stopped vehicle, could further enhance the capabilities of these safety applications. However, these scenarios assume nearly 100% penetration of connected vehicles, which is unrealistic in the near term.

Similarly, use of slower, high-latency communication methods, such as cellular communications, were considered and, while not precluded from the scenario, were not explicitly incorporated.

Finally, these applications focus on alerting/warning the driver of the primary vehicle involved in any of the potential crash scenarios and do not provide alerts or warnings to secondary vehicles. For instance, in the case of SSGA, 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 crossing 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. Concepts for the Proposed System

This section describes the proposed V2I safety applications (RLVW, SSGA, and CSW) 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 unequipped 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: Red-Light Violation Warning (RLVW)

The connected vehicle RLVW[25] safety application is a cooperative vehicle and infrastructure system that helps drivers avoid crashes at signalized intersections by warning the vehicle driver that a red-light signal violation is predicted to occur.

[25] 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.

RLVW Background

There were about 6,700 fatalities in intersection area crashes in the U.S. in 2009 with about 2,300 of those fatalities at signalized intersection crashes.[26] While the RLVW application is presently envisioned to address only signalized intersection violations, its implementation is expected to improve intersection safety for all drivers at signalized intersections.

An analysis of relevant NHTSA crash databases shows that violation crashes have a variety of causal factors. The RLVW application is intended to address the causal factors that include driver distraction;[27] obstructed/limited visibility due to weather or intersection geometry or other vehicles; the presence of a recently installed traffic signal at an intersection; and driver judgment errors. Driver warnings, such as those planned for RLVW, 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 RLVW application under the name "CICAS Limited to Stop Sign and Traffic Signal Violations (CICAS-V)" in a cooperative agreement program between the CAMP VSC2 Consortium (Mercedes Benz Research and Development North America, Inc., Ford, GM, Honda and Toyota), along with the Virginia Tech Transportation Institute (VTTI), the Intelligent Transportation System (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.

RLVW Goals and Objectives

As stated earlier, the goal of RLVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at intersections by warning the vehicle driver that a signal violation is predicted to occur. An equipped vehicle approaching an equipped intersection receives messages about the intersection geometry, SPaT information, 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 signal such that the vehicle enters the intersection during the red phase. While the system may not prevent all crashes through such warnings, it is expected that, with an effective warning, the number of signal violations will decrease, and result in a decrease in the number and severity of crashes at signal controlled intersections.

Specific goals of RLVW include the development of a cooperative vehicle-infrastructure signal violation warning system that:

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

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

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

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

- Reduction in frequency and severity of crashes at RLVW intersections
  - Measures:
    - Direct: Reduction in crash frequency and severity
    - Surrogate: Reduction in traffic signal 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 traffic signal or a dynamic message sign
  - Measures: Effectiveness, user acceptance, understanding, and usability.

RLVW Vision

RLVW 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 red-light 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 "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 RLVW equipped intersections and vehicles.

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

The initial implementation of the RLVW 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.

Increased market penetration and deployment of vehicle-sensing equipment at intersections to detect non-equipped vehicles will enable the development of cooperative systems that help avoid crashes based on erroneous gap assessment by drivers, such as left turn crossing path crashes. These cooperative systems would also warn the driver of the vehicle that has the right of way.

Complete 100% penetration of equipped vehicles might reduce the need for sophisticated car sensing infrastructure at the intersection. Drivers would be warned of impending multi-vehicle collisions based almost entirely by data from other vehicles with limited need for infrastructure data.

5.1.2 Proposed Application: Stop Sign Gap Assist (SSGA)

The SSGA application provides a driver timely, relevant information regarding unsafe conditions at a stop-controlled intersection, with the premise that the driver is already aware of the stop sign intersection (stop sign violation warning would be performed by a separate application). The purpose of the SSGA application is to provide information to enable a driver to make a more informed decision regarding when it is unsafe to proceed through the intersection (i.e., gap rejection), but not make the decision for the driver.

SSGA Background

Crashes in rural areas are typically more severe than in urban areas due to higher speeds. Nationally, although most crashes occur in urban areas, more than half of the fatal crashes occur in rural areas. Although more than half of the stop-sign related crashes occur in urban areas, in 2009, about 56% of the fatal crashes occurred in rural parts of the country.[28] In 2009, there were over 2,200 fatal crashes at stop-sign controlled intersections. Fatalities and injuries resulting from stop-sign related crashes cost approximately $28 billion annually.

To combat this problem, research has been done to develop safety applications that provide the driver alerts and warnings. This foundational research for the development of a SSGA safety application, called CICAS-Stop Sign Assist (CICAS-SSA), was led by the Minnesota Department of Transportation (Mn/DOT) and the University of Minnesota. The application targets the national problem of crashes at stop-sign controlled intersections; particularly those where lower speed, lower volume roads intersect high speed, high volume freeways with at-grade crossings. The CICAS-SSA project primarily evaluated information delivery via roadside signing, but also builds upon previous research to facilitate cooperative vehicle-infrastructure components that are aligned with connected vehicle technology. For example, the alerts and warnings developed through CICAS-SSA involve two-way communication between the vehicle and the infrastructure. Furthermore, CICAS and other connected vehicle applications will use state map (situational awareness) information (i.e., roadway geometry, vehicle speed and location information, and traffic control device information as well as possibly other vehicle dynamic information) to perform their functions. CICAS-SSA examined various options for what, when, and how data would be cooperatively shared between the vehicle and the roadside infrastructure. One option considered having the infrastructure to perform threat assessments, and warn affected drivers via roadside or onboard signing. Another option considered was to provide the state map electronically to properly equipped vehicles, thereby allowing vehicles to perform threat assessments and deliver onboard warnings.

A three-year research effort developed a gap algorithm and Driver Infrastructure Interface (DII) for algorithm validation. The research effort also examined the role of system architecture and how it affects two-way communication between the vehicle and infrastructure, which is essential to both infrastructure and vehicle-based driver interfaces. The second component of CICAS-SSA was a field operational test (FOT) under which the safety benefits and driver acceptance of the system were validated. Research and field testing were conducted at the intersections of U.S. 52 and County State Aid Highway (CSAH) 9 in Goodhue County, Minnesota; U.S. 53 and Wi 77 in Washburn County, Wisconsin; and U.S 169 and CSAH 11 in Mille Lacs County, Minnesota. These SSA deployments have reduced, although not eliminated, right-angle crashes, as shown in Table 5-1, and aided drivers traveling through the intersection during inclement weather conditions, such as fog. Most remaining

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

right angle crashes appear to be at the far side of the intersection where the minor road vehicle did not pause in the median at the yield sign.

Table 5-1. Summary of Right Angle Crashes at Intersections with Stop Sign Assist

Site	Right Angle Crashes (and rate) Prior to System Activation	Right Angle Crashes (and rate) After System Activation	Activation Date
US 52 and CSAH 9, Goodhue County, MN	17 during the period 2007-2009 (5.6 crashes/year)	8 (3.4 crashes/year)	January 20, 2010
US 53 and Wi 77, Washburn County, WI	11 during the period 2003-2009 (1.5 crashes/year)	2 (0.96 crashes/year)	April 21, 2010
US 169 and CSAH 11, Mille Lacs county, MN	19 during the period 2007 – May 2011 (4.2 crashes/year)	3 (2.8 crashes/year)	April 3, 2011

The connected vehicle V2I safety application described in this ConOps document is an extension of the CICAS-SSA application, now called simply SSGA.

SSGA Goals and Objectives

The goal of SSGA is to improve safety at stop sign controlled intersections by providing a cooperative decision support system to help drivers safely negotiate such intersections. The system will support the minor-road driver in identifying unsafe gaps in major road traffic at the intersection, assisting with either crossing or entering the major road traffic from a minor road. However, the system will not replace drivers' gap decision-making process; instead, it provides useful information and the driver remains responsible for choosing a safe gap and safely crossing the intersection. Also, this system only identifies unsafe gaps and has limited benefits when continuous major road traffic provides no safe gaps for minor road vehicles to proceed through the intersection. If this is a recurring situation, other measures may be required (e.g., installation of a traffic signal, pushing minor road drivers to a different intersection by prohibiting through and left turn traffic, etc.). This application does not include warnings to major road drivers of minor road vehicles crossing or entering the path of major road vehicles. A separate V2V or V2I application with minor road vehicle detection might include this feature.[29]

SSGA Vision

The vision for SSGA is wide deployment at stop sign controlled intersections that have significant crash rates so as to reduce crashes and severity through improved gap assessment by drivers. It is envisioned that the initial SSGA application will be deployed at intersections with the greatest safety problems and that the application will initially be primarily infrastructure-based to provide benefits to all drivers (i.e., for both equipped and non-equipped vehicles). Information and warnings will be provided via a DII (e.g., one or more dynamic signs) located at the intersection. For equipped vehicles, an incremental advance in SSGA functionality may include providing information to the driver inside the vehicle through a driver-vehicle interface (DVI). This could purely be a "onboard signing" capability that displays a stop or yield sign, for example, or potentially a vehicle-generated message based upon onboard processing of data provided from the SSGA infrastructure components. The onboard SSGA

[29] The V2V intersection movement assist application performs this function.

application may provide information and warning timings that are consistent with DII displays, but specifically tailored to the vehicle and driver environment.

As more and more vehicles become equipped with connected vehicle capabilities, the ultimate vision for SSGA is to become primarily a vehicle-based system supported through V2V communications and onboard DVIs. This would enable ubiquitous SSGA services and other vehicle collision avoidance services independent of supporting infrastructure components, thus allowing coverage on all roadways and intersections. It is acknowledged that for gap acceptance related crashes, a very high market penetration of equipped vehicles is necessary in order to provide these services due to the need to be aware of the location of all vehicular traffic on the roadway. Regardless of the market penetration of connected vehicle technology in passenger vehicles, trucks, and buses, infrastructure-based vehicle detection may be required in rural areas where farm equipment and other unequipped vehicles may create hazards.

5.1.3 Proposed Application: Curve Speed Warning (CSW)

The CSW application is intended to improve roadway curve safety and reduce run-off-road (ROR) and rollover events by alerting drivers if their speed may cause loss of vehicle stability and/or control in the curve.

CSW Background

The need for this application is based on the possibility of excessive speed in a curve leading to loss of vehicle control, ROR, collision, and/or rollover events. Any of these events can, alone or in combination, result in vehicle or property damage or loss, injury, or death.[30] Road departure crashes[31] are considered among highway crashes most likely to result in fatalities. Based on the Transportation Research Board (TRB) report from National Cooperative Highway Research Program (NCHRP) Project 17-18(3), nearly 4 of every 10 fatal motor vehicle crashes—well over 14,000 a year—involve a single vehicle leaving the roadway. There are more than twice as many ROR fatal crashes on rural roads than on urban roads. Some 42 percent of ROR fatal crashes occur on curves (50 percent in rural areas). The life-threatening events most likely to occur are rollovers (42 percent) and collisions with trees (25 percent). Incidents occurring on rural roadways are particularly dangerous due to factors including high travel speeds, long emergency response times, the potential for severe weather conditions, few alternative routes, long distances between destinations, and the presence of drivers unfamiliar with their surroundings or driving on rural roadways.[32]

CSW systems have been included in various crash warning systems since the USDOT implemented the IVI Program in 1997. Since then, multiple crash warning systems (which include CSWs) have been proposed, developed, and tested for the purpose of providing drivers advance warning to reduce speed before approaching sharp curves.

Upon its completion in 2005, the IVI Program led to additional research efforts including the Integrated Vehicle-Based Safety Systems (IVBSS) Initiative and the Vehicle Infrastructure Integration (VII) Initiative. Under the umbrella of both of these programs, CSW systems were developed and

[30] Vehicle Safety Communications Project Task 3 Final Report Identify Intelligent Vehicle Safety Applications Enabled by DSRC, (CAMP)

[31] Defined as crashes in which the first harmful event occurs off the roadway. This includes crashes caused by loss of control while negotiating a curve.

[32] IntelliDrive Rural Risk Warning System (IRRWS): A North/West Passage Rural Vehicle Infrastructure Integration Demonstration Project Final Report. (Western Transportation Institute, Montana State University)

evaluated. Both of these programs were precursors to the current connected vehicle research underway within the USDOT.

Integrated Vehicle-Based Safety Systems (IVBSS) Program

The IVBSS Program was a five-year cooperative research agreement between USDOT and a private consortium led by the University of Michigan Transportation Research Institute (UMTRI) to build and field test an IVBSS designed to prevent rear-end, lane change/merge, and ROR crashes. The prototype vehicles developed provide forward collision warning (FCW), lane departure warning (LDW), lane change warning (LCW), and CSW functions to enhance light vehicle/passenger vehicle and heavy vehicle/truck safety.

The project included designing, building, laboratory testing, field operational testing, and evaluation of prototype systems on passenger vehicles and heavy trucks to assess the efficacy of the system in reducing crashes and incidents.[33]

Vehicle Infrastructure Integration (VII) Program

The VII Program, which has evolved into the Connected Vehicle Research Program for USDOT, aimed to combine wireless communication, onboard computer processing, smart infrastructure and other components to provide communication between vehicles and infrastructure. CSW was identified as one of the “day one” applications that could be functional on the first day of VII operation.[34]

Connected Vehicle Research Program

According to USDOT RITA, the underlying goal of this program is “the development and deployment of a fully connected transportation system that makes the most of multi-modal, transformational applications. [This deployment] requires a robust, underlying technological platform. The platform is a combination of well-defined technologies, interfaces, and processes that, combined, ensure safe, stable, interoperable, reliable system operations that minimize risk and maximize opportunities.”[35] Research on curve warning applications fits under the V2I communications for safety application area of the program, which encompasses intersection safety; ROR; speed management; and commercial/transit vehicle enforcement and operations for safety applications.

In addition, as part of AASHTO’s Connected Vehicle Infrastructure Deployment Analysis findings, it was recommended that applications for curve speed and ROR warnings be considered.[36]

The USDOT has launched a connected vehicle Safety Pilot Model Deployment program where it will test wireless connected vehicle warning devices with ordinary drivers in normal roadway situations. The Safety Pilot program includes driver clinics where motorists will be monitored in a controlled environment, and a model deployment during which drivers will test the safety technology with volunteer drivers in one geographic region without any restrictions. Simple V2I CSW applications will be part of this testing. The Safety Pilot program will help determine how ordinary motorists respond to

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[33] http://www.its.dot.gov/ivbss/

[34] http://www.its.dot.gov/research_docs/pdf/8cost-analysis.pdf

[35] http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm **(US DOT, RITA)**

[36] http://ntl.bts.gov/lib/43000/43500/43514/FHWA-JPO-11-090_AASHTO_CV_Deploy_Analysis_final_report.pdf

new safety warnings in their vehicles and how accepting they are of this technology. The project will test the effectiveness of the technology in different driving environments in the U.S.[37]

The concepts described in the section below combine the research conducted on the IVBSS, VII, and Connected Vehicle Research Programs along with the implications of human behavior, vehicle dynamics, and weather conditions to identify a system to efficiently and effectively warn drivers to reduce speed for safe navigation on approaching curves.

CSW Goals and Objectives

The goal of the CSW application is to improve roadway curve safety and reduce ROR and rollover events by alerting drivers that their speed exceeds a safe threshold for current curve and roadway conditions and may cause loss of vehicle stability and/or control in the curve. This application is intended to use both vehicle-based and infrastructure-based sensor data to assess safe speeds based upon curve geometry, real-time road and weather conditions, vehicle telematics data, and vehicle configuration data. When deployed, the application is intended to:

- Reduce the number of roadway fatalities
- Reduce the number and severity of roadway injuries
- Reduce property damage associated with roadway incidents.

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 Proposed Application: Red-Light Violation Warning (RLVW)

Operational Policies

OP-RLVW-01. RLVW will be capable of using the emerging Connected Vehicle technologies, as defined by USDOT, as its enabling foundation

OP-RLVW-02. DELETED

[37] http://www.its.dot.gov/research/safety_pilot_overview.htm

OP-RLVW-03. RLVW 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 system.

OP-RLVW-04. Any vehicle with an onboard RLVW system implemented will be able to inform the driver when the onboard RLVW system is not working.

OP-RLVW-05. RLVW will not require the system to recognize the presence of pedestrians, bicyclists, and other vehicles moving in and around the intersection. Pedestrians may benefit, but RLVW has no specific countermeasure(s) to protect pedestrians, bicyclists, or other vehicles.

OP-RLVW-06. RLVW will not attempt to warn the driver if the vehicle has safely stopped at the intersection, in accordance with local traffic laws, and subsequently completes a legal maneuver. A legal turn on red typically requires a full stop by the vehicle and thus would not be affected by the application. A rolling stop still requires a vehicle to slow to a safe speed, and, for situations where this is a legal maneuver, will not be construed as a violation by the application.

OP-RLVW-07. 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 this application shall follow the message priority approach as recommended in Annex A of SAE J2735:2009.

OP-RLVW-08. The integrity of the data provided by the enabled intersection shall be maintained.

OP-RLVW-09. The functioning of the RLVW application shall not violate existing federal, state, or local agency policies.

OP-RLVW-10. The RLVW application applies to most intersection geometries. The interface solutions apply to most four-leg and three-leg intersections regardless of specific geometry. This is important because designing for specific intersection geometries would reduce the extent to which the solutions generalize to other intersection.

OP-RLVW-11. Minimal training is required for drivers to use the RVLW 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-RLVW-12. The infrastructure components are available to transmit the required information to vehicles 24 hours a day.

OP-RLVW-13. No unwarranted notification is provided to the driver. Warnings are only issued if the vehicle component of the RLVW application determines that the vehicle is likely to violate the traffic signal. A companion application may inform the driver of gaps in oncoming traffic for signalized left turn assist (SLTA), for example.

Operational Constraints

OC-RLVW-01. Not all signalized and/or connected intersections will have RLVW capabilities. This is due to the large number of signalized intersections and the time and cost associated with identifying them as RLVW intersections. Even if other connected vehicle applications are in place at an intersection, the roadside equipment may not support RLVW. State and local DOTs, in cooperation with the USDOT, must determine which signalized intersections warrant RLVW and prioritize their installation.

~~**OC-RLVW-02. Not all connected intersections will have RLVW capabilities.** Even though other connected vehicle applications may be in place at an intersection, the roadside equipment may not support RLVW.~~

OC-RLVW-03. Not all RLVW intersection equipment will have continuous network connectivity. Some intersections in isolated or remote regions may not maintain a permanent network connection to a central traffic/transportation management center, but instead, use a dial-up modem or similar method to be establish temporary network connectivity. As such, the RLVW intersection equipment will not necessarily have continuous access to backend services (such as for security validation and software updates).

OC-RLVW-04. Not all vehicles will be RLVW 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-RLVW-05. The RLVW system will not require any driver-specific customization or learning feature in the initial deployment. The violation warning will not be tailored to drivers' individual driving habits.

OC-RLVW-06. The RLVW 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 will be enhanced to include all available, relevant information.

OC-RLVW-07. The RLVW application is single-vehicle based and does not require the detection of other vehicles. The RLVW application accounts only for the equipped vehicle. The system does not require accounting for other vehicles on the roadway. RLVW does not require providing warnings of an impending crash with other vehicles. This information may be addressed through other applications.

OC-RLVW-08. Driver-vehicle interface may not be uniform across different vehicles models. The warning provided to the driver by the equipped vehicle may vary between vehicle models and OBE suppliers. The look and feel of the warning is dependent on the design selected and installed by the onboard system supplier and/or vehicle manufacturer.

5.2.2 Proposed Application: Stop Sign Gap Assist (SSGA)

Operational Policies

OP-SSGA-01. SSGA application applies to most intersection geometries. The interface solutions apply to most stop sign controlled, four- or three-leg intersections with or without a median, regardless of specific geometry. This is important because designing for specific intersection geometries would reduce the extent to which the solutions generalize to other intersections.

OP-SSGA-02. System does not impede traffic on the major road. The SSGA system should have minimal adverse effect on major road traffic speeds and volumes. Drivers heeding the advice of the SSGA system should produce less than a 10% variation in major road traffic speed. When computing safe sightlines for intersections[38], a 30% decrease in speed is allowable by AASHTO guidelines. However, 30% speed variations would adversely affect traffic flow on the major road.

OP-SSGA-03. Minimal training is required for drivers to use the SSGA 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-SSGA-04. Minimal additional signage is required. Additional signage may be needed to explain how the system works. To minimize cognitive overload, the number and complexity of the signs will be limited.

OP-SSGA-05. 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 system 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-SSGA-06. Messages are visible during day and at night. The interface solutions are visible both during the day and at night.

OP-SSGA-07. The SSGA application does not interfere with existing traffic control devices. The interface solutions complement and do not interfere with existing traffic control devices. Obscuring a stop sign by placing an SSGA display in front of it would be an example of interfering with an existing traffic control device.

OP-SSGA-08. The SSGA application monitors major road traffic that exits at the minor road. Major road traffic that is slowing to turn (i.e., enter the intersection) should be monitored.

OP-SSGA-09. The SSGA application benefits all vehicles. System provides some level of service to both equipped and unequipped vehicles, as well as both passenger and commercial vehicles.

OP-SSGA-10. The SSGA application responds to every major road vehicle. The system is capable of reliably identifying and monitoring every major road vehicle as it approaches the intersection.

OP-SSGA-11. SSGA will be capable of using the emerging Connected Vehicle technologies as defined by USDOT as its enabling foundation.

OP-SSGA-12. For any vehicle with an onboard SSGA application implemented, the driver will be aware if the onboard SSGA application is not working.

OP-SSGA-13. SSGA will not require the system to recognize the presence of pedestrians and bicyclists moving in and around the intersection. Pedestrians may benefit, but SSGA has no specific countermeasure(s) to protect pedestrians or bicyclists.

[38] "A Policy On Geometric Design of Highways and Streets (4th ed)", Washington, DC: AASHTO

OP-SSGA-14. 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.

OP-SSGA-15. The integrity of the data provided by the enabled intersection shall be maintained.

OP-SSGA-16. The functioning of the SSGA application shall not violate existing agency policies.

OP-SSGA-17. The infrastructure components are available to transmit the required information 24 hours a day.

OP-SSGA-18. The roadside infrastructure is maintained by the agency or private-public partnership responsible for the roadway 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-SSGA-19. 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 DII signage to safely navigate an upcoming curve. Non-equipped vehicles will not have access to onboard application components. Infrastructure components will detect non-equipped vehicles on the major road.

Operational Constraints

OC-SSGA-01. The minor road driver is only provided assistance in decision-making. Regulatory signs at the intersection control traffic flow; the SSGA system 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 will therefore reduce the likelihood that the same type of crash occurs. Alerts and warnings to major road drivers might be provided with a separate safety application about minor road vehicles entering or crossing the major road vehicle path.

OC-SSGA-02. The system assumes that the minor road driver obeys regulatory signing. The interface solutions assume that the minor road driver stops before proceeding through the intersection. The SSGA application is not intended to address situations where minor road drivers violate the regulatory signing (willfully or due to inattention). A secondary benefit of some solutions is that the interface could increase the conspicuity of the intersection and reduce the likelihood of unintended regulatory sign violations.

OC-SSGA-03. The system uses only a prohibitive frame. All the interface solutions use a prohibitive framework (e.g., "Unsafe to turn left or cross"). This is important because a permissive framework has increased liability if compliance leads to a crash[39].

OC-SSGA-04. Not all stop-controlled and/or connected intersections will have SSGA capabilities. This is due to the large number of non-signalized intersections and the time and cost

[39] Donath, M., & Shankwitz, C. (2001). Infrastructure consortium proposal for intersection decision support, Volume 3: The Minnesota program. Minneapolis, MN: Center for Transportation Studies.

associated with implementing SSGA at intersections. Even though other connected vehicle applications may be in place at an intersection, e.g., a stop sign violation warning, the roadside equipment may not support SSGA. State and local DOTs, in cooperation with the USDOT, must determine which non-signalized intersections warrant SSGA and prioritize their installation.

OC-SSGA-05. Not all SSGA intersection equipment will have continuous network connectivity. As such, the SSGA intersection equipment will not necessarily have continuous access to backend services (such as for security validation and software updates).

OC-SSGA-06. Not all vehicles will be equipped with connected vehicle technology. It is understood that an initial deployment without the inclusion of DII will only benefit connected vehicles, and that a comprehensively connected vehicle environment will take many years to occur.

OC-SSGA-07. The SSGA application will be limited by the amount of data available in the initial deployment. The alerts and warnings will not be tailored to drivers' individual driving habits. As data becomes available for the application over time, the alerts and warnings may be enhanced to include all available, relevant information.

OC-SSGA-08. The driver vehicle interface may not be uniform across different vehicles models. The warning provided to the driver by the equipped vehicle may vary. The look and feel of the warning is dependent on the design selected and installed by the onboard system supplier and/or vehicle manufacturer.

5.2.3 Proposed Application: Curve Speed Warning (CSW)

<u>Operational Policies</u>

OP-CSW-01. The infrastructure components are available to transmit the required information 24 hours a day.

OP-CSW-02. Roadside infrastructure is maintained by the agency or private-public partnership responsible for the roadway 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/partnership's behalf).

OP-CSW-03. 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 roadway curve warning signage to safely navigate an upcoming curve. Non-equipped vehicles will not have access to vehicle CSW application components.

OP-CSW-04. Safe speed 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 curve. While this does not preclude the infrastructure from displaying a general warning, only the equipped vehicle would present vehicle-specific safe speed.

OP-CSW-05. No notification is provided to the driver when driving at an appropriate speed. Warnings are only issued if the vehicle component of the CSW application determines that the vehicle exceeds the safe speed in the curve. A companion application may inform the driver of an upcoming curve as a navigational aid, but that is distinct from a CSW.

OP-CSW-06. The DVI should provide system status information to drivers.

OP-CSW-07. CSW will be capable of using connected vehicle technology.

OP-CSW-08. For any vehicle with an onboard CSW application implemented, the driver will be informed if the onboard CSW application is not working.

OP-CSW-09. 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.

OP-CSW-10. DII is robust to 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 system 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-CSW-11. Messages are visible during day and at night. The interface solutions are visible both during the day and at night.

OP-CSW-12. The SSGA application benefits all vehicles. System provides some level of service to both equipped and unequipped vehicles, as well as both passenger and commercial vehicles.

Operational Constraints

OC-CSW-01. 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 RSE installations. This decision will be based on several factors, which include (but are not limited to): pre-existing infrastructure, retrofit capabilities, historic curve incident data, and crash potential. Note: Assuming that future funding becomes available, equipment installation is expected to continue across the country.

OC-CSW-02. The CSW application results will be limited by the amount of data available for calculating safe speed. Customization for individual driving habits, for example, will not be required for initial deployment. As data becomes available to the application over time, the safe-speed algorithm will be enhanced to include all available, relevant information.

OC-CSW-03. The CSW application is single-vehicle based and does not detect other vehicles. The vehicle CSW application accounts only for the equipped vehicle. The system does not account for other vehicles on the roadway. It does not provide warnings of an impending crash with other vehicles. This information may be addressed through other applications.

OC-CSW-04. DELETED

OC-CSW-05. Driver vehicle interface may not be uniform across different vehicles models and equipment suppliers. The warning provided to the driver by the equipped vehicle may vary with vehicle model and equipment supplier. The look and feel of the warning is dependent on the design selected and installed by the onboard system supplier and/or vehicle manufacturer.

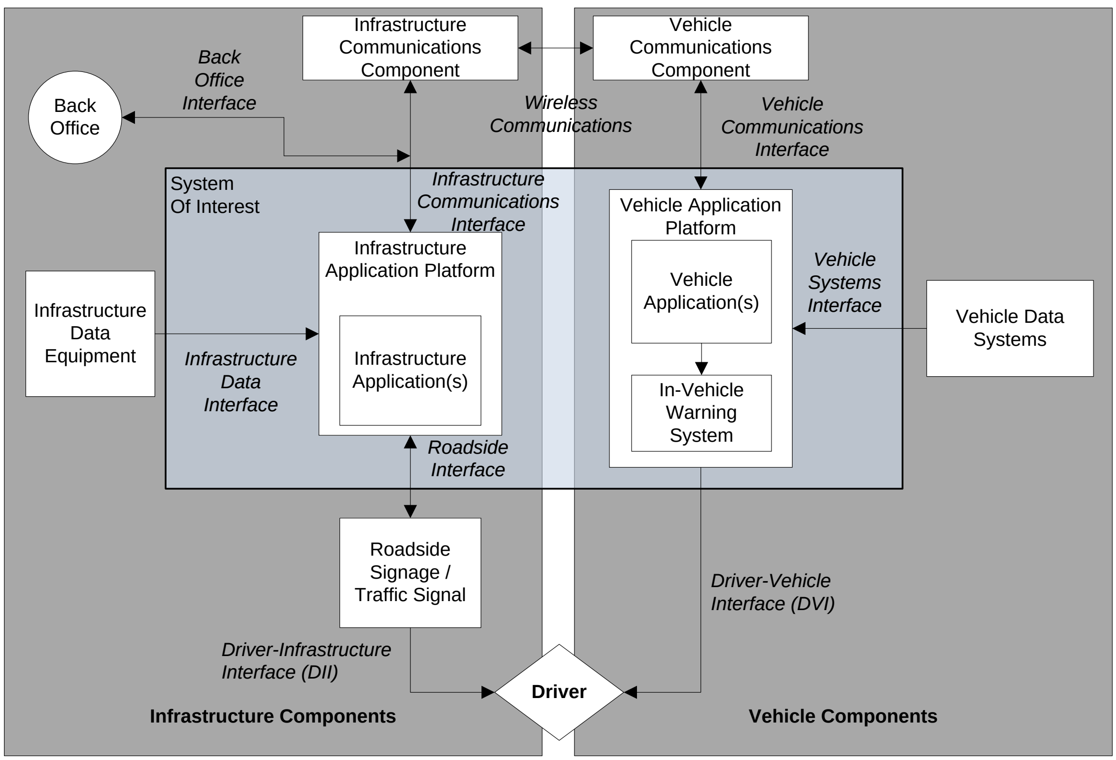
OC-CSW-06. DELETED

OC-CSW-07. The system uses only a prohibitive frame. All the interface solutions use a prohibitive framework (e.g., “Curve Ahead/Reduce Speed”). This is important because a permissive framework has increased liability if compliance leads to a crash (see Donath and Shankwitz, 2001).

OC-CSW-08. Not all vehicles will be equipped with connected vehicle technology. It is understood that an initial deployment without the inclusion of DII will only benefit connected vehicles, and that a comprehensively connected vehicle environment will take many years to occur.

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. It includes both the vehicle and infrastructure platforms that house the applications. The intended System-of-Interest (SOI) is a platform that will support one or more safety applications. More specific diagrams of individual safety applications are presented in the subsections below.



Source: Battelle

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

As shown in Figure 5-1, many components make up the SOI, the supporting components and ultimately, the end user (the driver):

- 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 maintainer 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 even 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/Traffic Signal

An integral part of the infrastructure interface with the driver is Roadside Signage and/or Traffic Signal. Roadside Signage and Traffic Signal provide 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 information to the Vehicle Application. Information 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: Red-Light Violation Warning (RLVW)

The RLVW application framework is depicted in Figure 5-2, and mirrors the general framework diagram above.

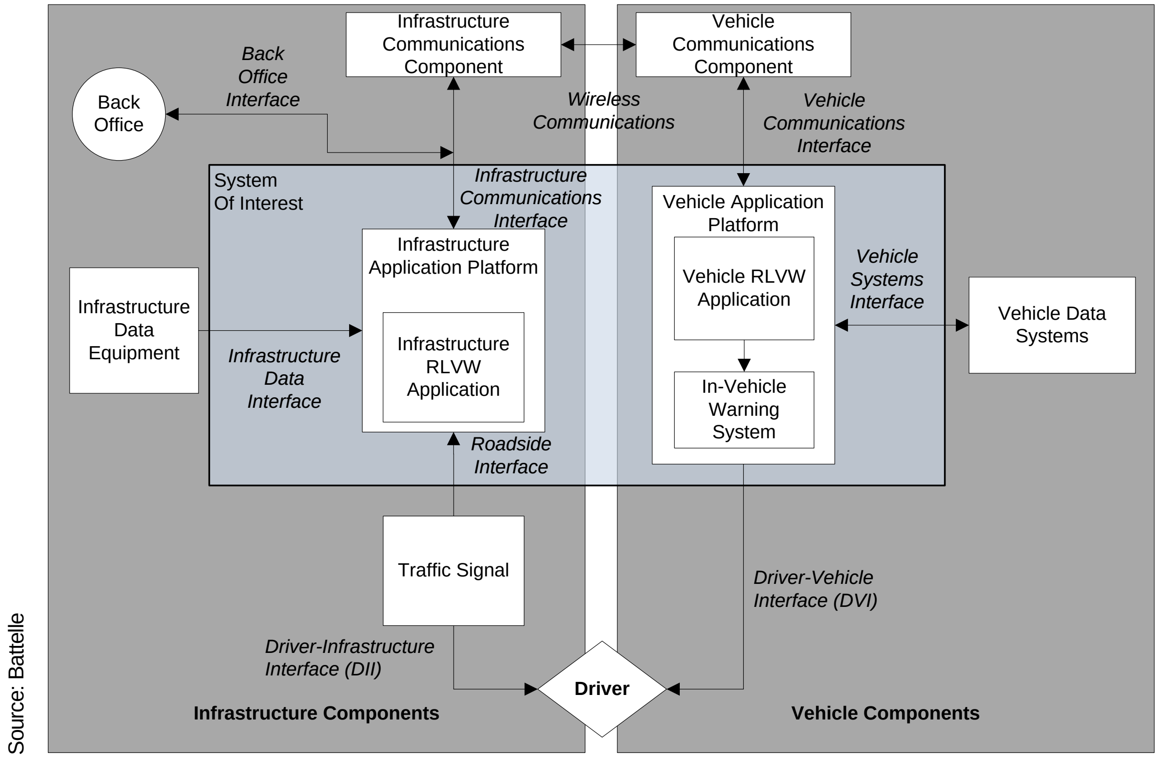


Figure 5-2. Red-Light Violation Warning Application Diagram

RLVW capabilities are dependent on the cooperation of infrastructure and vehicle components to achieve the system's operational objectives. The paragraphs below discuss what capabilities are present when RLVW equipment is deployed at a signalized intersection. For each RLVW signalized intersection, the infrastructure RLVW application broadcasts messages that include, but are not limited to, the following:

1. SPaT data
2. Intersection geometry information messages
3. A positioning correction message (Optional)
4. Road surface information and other weather-related data if available (Optional)
5. An RLVW 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. *SPaT Data:* The RLVW infrastructure data equipment broadcasts a message containing SPaT data. The SPaT message contains information and current status on the phase and timing of all the signals for each approach in the intersection. This message, together with the intersection geometry information, will enable the vehicle to determine which signal

indication applies to it and use this information for determining whether a warning is warranted.

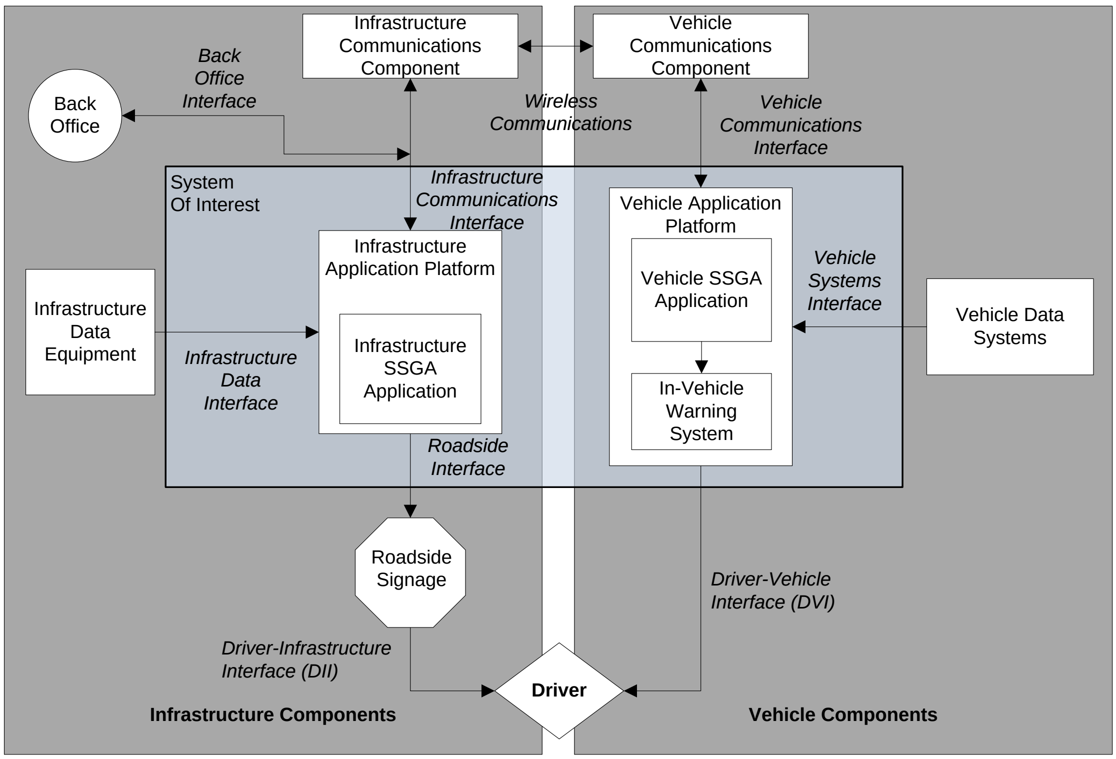
2. *Intersection Geometry Information Messages:* This message contains the intersection information including intersection ID, road/lane geometry for all approach roads (e.g., geometric intersection design, or GID), location of stop lines, and lane numbering scheme associated with movements.
   a. The 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 in case it receives simultaneous messages from multiple intersections. The vehicle needs the road/lane geometry to match itself to the approach road and the specific lane[40] 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. The lane numbering scheme has to correspond to the traffic SPaT scheme so that the vehicle can determine which signal information is pertinent.
   b. An intersection's RLVW equipment must be placed at a point along the travel path to the intersection where it can complete transmission of intersection geometry information updates in time for basic safety assessment algorithms to decode the information and calculate the likelihood of a traffic control violation.
3. *Positioning Correction Message (Optional):* This message contains the global positioning system (GPS) positioning correction information for the intersection that the vehicle may use to improve its estimate of location within the intersection.
4. *Road Surface Information and Other Weather-Related Data (Optional):* RLVW equipment might transmit information to the vehicle about the road surface coefficient of friction at the intersection, weather related data such as dew point, temperature, visibility, rain, etc. that may assist the onboard RLVW system in adjusting warning timing to account for variations in stopping distance.
5. *Service Announcement (Optional):* The service announcement provides vehicles with the intersection's identification (ID) code number and indicates whether the intersection's RLVW 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 as the application instead could simply continuously broadcast SPaT and intersection geometry information messages that would inherently indicate the RLVW capabilities of the intersection and availability of information.

When an RLVW equipped vehicle approaches an RLVW equipped intersection, the actions that the vehicle performs depend on whether the intersection has RLVW infrastructure components. Assuming the intersection has RLVW equipment with normal functionality, the RLVW equipment receives and processes all available data regarding both the vehicle and intersection, providing the driver a warning about a potential red-signal violation. However, the vehicle also has to determine whether it has detected any problems with that equipment.

[40] 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.

5.3.2 Proposed Application: Stop Sign Gap Assist (SSGA)

Figure 5-3 presents an overview of the SSGA 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 the vehicle components are not necessary for initial SSGA deployments, but will become more prevalent as more vehicles become part of the connected vehicle environment.



Source: Battelle

Figure 5-3. Stop Sign Gap Assist Application Diagram

Detecting vehicle presence through the infrastructure data equipment is necessary for the major road and may be used on the minor road. This component may consist of any detection product (i.e., inductive loops, radar, lidar, cameras, etc.) that can track and anticipate vehicle location. This information is essential to determine unsafe gaps and when the system should transmit an alert or warning. There could be three separate roadside detection subsystems: the major road subsystem, which is required, and the optional minor road and median subsystems. The major road subsystem must track and anticipate vehicle location. The optional minor road and median subsystems might gather additional data to enhance the application with relevant information, which might include minor road vehicle presence, classification (based on size), and position.

The major road vehicle detection system is responsible for determining the present status of the intersection in terms of gaps in cross-traffic. The major road vehicle detection system sensors detect the presence, distance, and speed of each vehicle within its coverage zone, and from that the roadside application computes when conditions are unsafe for that minor road driver to proceed into the intersection. When unsafe conditions are detected, the driver is warned via the DII and (if available) DVI.

The optional minor road and median subsystems could enhance the driver alerts and warnings. The median presence detection system could monitor the occupancy of the median crossroads. If a vehicle is detected to be in the crossroads, the system would indicate to the driver on the minor road that it is unsafe to cross the traffic stream. This approach avoids both crossing path conflicts (the vehicle in the median facing the vehicle on the minor road) and occupancy conflicts (the vehicle on the minor road not having space in the median because another vehicle is present). The optional minor road subsystem would address another possible factor in unsafe gap detection: the size of the vehicle waiting on the minor road; longer vehicles or those with slower acceleration capabilities may require larger gaps to safely cross or enter major road traffic. Minor road sensors could determine vehicle presence, size, and position in order to potentially more accurately and reliably warn drivers of unsafe conditions to enter the intersection.[41]

There are a number of options for more driver-specific warnings. One option involves the vehicle sending relevant vehicle and driver information (e.g., vehicle type, driver age, preferred lag length) to the roadside unit computing alerts and warnings, thereby optimizing the system performance for a particular driver. The architecture also allows for this roadside equipment to provide intersection status data to connected vehicles for onboard processing; the vehicle onboard unit uses this dynamic information and its own algorithm to compute the alert and warning status for the DVI. If the vehicle “knows” driver preferences, the DVI alerts and warnings can be optimized at a high level for a particular driver.

The SSGA application collects all available sensor information (major road, minor road, and median sensors) data and computes the dynamic state of the intersection. Depending on system architecture, this dynamic state data can be used by either the roadside application unit or the vehicle application unit to assess the threat to the minor road driver and to issue appropriate warnings and alerts. The application may be equipped with local data storage devices or network connections to allow time histories or crash/near crash events to be captured for further analysis.

The DII will provide information to drivers to indicate when conditions are unsafe to cross or enter the major road traffic (e.g., this might be a variable message sign or a static sign with variable elements). The timing and content of the DII sign is controlled by the roadside unit.

The DVI/Onboard Warning System will be located in the vehicle, and will provide information indicating an unsafe condition to a driver located on the minor road. In one realization (roadside computed alerts and/or warnings), information (e.g., vehicle operating conditions, driver age, etc.) is passed from the vehicle to the roadside unit, where the information would be used to modify the alert and warning timing. The roadside unit would then broadcast the appropriate alert or warning message to the vehicle, which would then activate the DVI. In another realization (onboard computed alerts and/or warnings), the roadside application would continuously broadcast dynamic intersection state data, and the vehicle application would use this dynamic state information to execute its threat assessment algorithm and activate the DVI at the appropriate time. Any onboard displays will be consistent with the DII signage and necessarily conform to both industry (e.g., OEM) and government (e.g., NHTSA) guidelines.

[41] Studies conducted by the University of Minnesota have concluded that vehicle class is not a relevant factor.

5.3.3 Proposed Application: Curve Speed Warning (CSW)

The CSW application framework is depicted in Figure 5-4 and mirrors the general framework included in Figure 5-1 above.

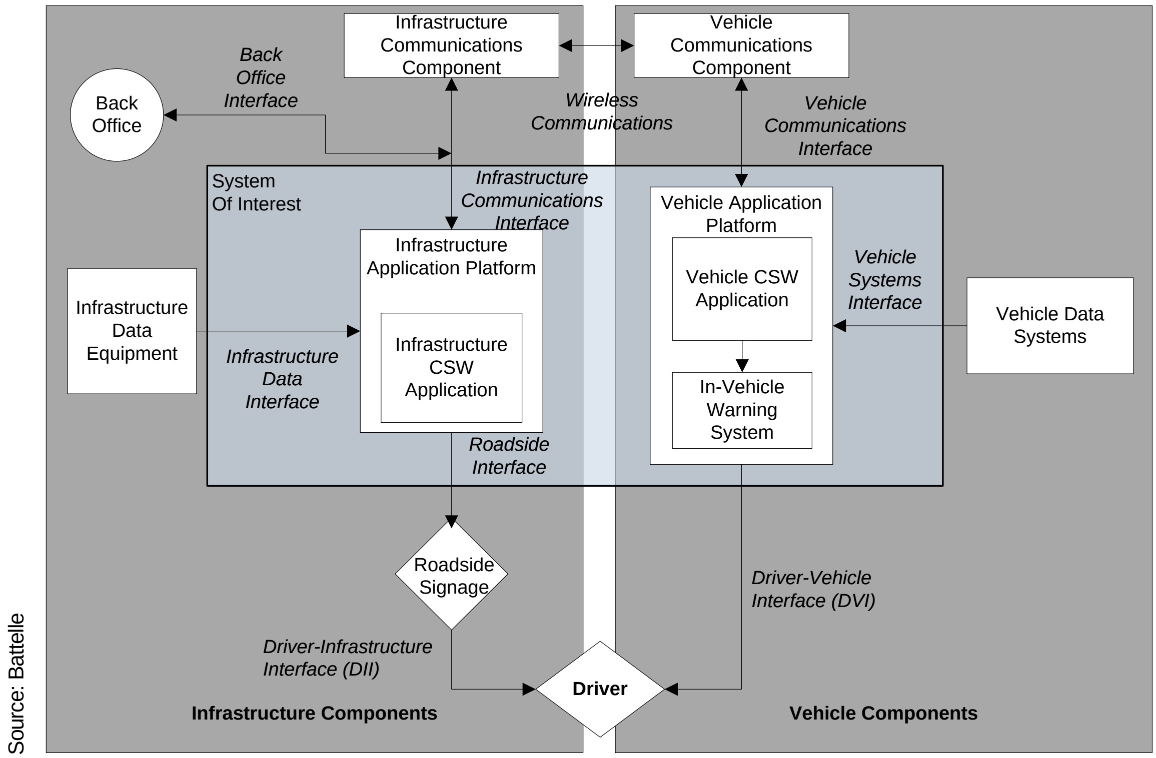


Figure 5-4. Curve Speed Warning Application Diagram

The infrastructure CSW application may receive and process information regarding the curve geometry including the radius of a curve, the corresponding roadway superelevation, and the slope as well as the roadway material and the posted curve speed limit. Other information may include real-time road and weather conditions. The Infrastructure CSW Application component may include one common hardware platform that will host one or more safety applications.

The algorithm run by the CSW vehicle application may take into account the following factors related to loss of vehicle control:

- Data provided by the CSW Infrastructure: road geometry (curve radius and superelevation), roadway material, posted curve speed limit, real-time weather and roadway conditions (current temperature, wet/icy road conditions, visibility limitations)
- Vehicle system data: detected vehicle speed and acceleration; detection of electronic braking system (EBS), anti-lock braking system (ABS), or traction control, vehicle telematics data, and vehicle configuration data.

Information provided by the vehicle data systems may come from a positioning system, vehicle data bus, sensors, actuators on the vehicle, stability systems, or other systems. Specific interfaces to vehicle systems will be dependent on specific information required to support the CSW application. Information sourced from these systems may include:

- Vehicle's speed and rate of acceleration (via the speedometer and accelerometer)
- Steering wheel angle
- Turn signal activation
- Interventions by the electronic stability control (ESC), ABS, or traction control.

The system information also includes vehicle telematics and configuration parameters.

5.4 Modes of Operation

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

5.4.1 Normal Operation

Red Light Violation Warning

For normal operations of the RLVW system, 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 variations for a number of intersection types, including:

- *Simple Traffic Signal Approach.* The RLVW enabled vehicle is approaching an RLVW enabled traffic signal at a simple intersection with no dedicated turn lanes, where all vehicles on the same approach have the same traffic signal indication.
- *Intersections with Dedicated Left or Right Turn Lanes.* The RLVW enabled vehicle is approaching an RLVW enabled intersection with multiple traffic signal indications on the approach.
- *Flashing Traffic Signal.* If an RLVW equipped traffic signal goes into flashing mode, the RLVW system will recognize the flashing indication (e.g., flashing red light) and broadcast the appropriate information in the message set sent to the vehicle.
- *Reduced Visibility.* There are two types of reduced visibility scenarios that RLVW must consider. 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 traffic control, 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 RLVW in the vehicle and in the intersection enables the driver to be alerted about the presence of the traffic control and alerted to the potential for a violation.

Stop Sign Gap Assist

System is working with normal capability such that information is presented on the DII. The only drivers affected by the SSGA system are those on the minor road, stopped at the intersection with the intent to either enter or cross the major road traffic. One example of the DII sign display might be an

MUTCD (Manual on Uniform Traffic Control Devices, 2009 edition) standard advisory or warning sign (e.g., MUTCD sign R6-3 or R6-3a). Appropriate alerts or warnings are given, possibly involving additional icons indicating cross-traffic. These displays would indicate to a driver that the system is active, and when the system predicts conditions are unsafe to cross or enter the main road traffic.

Curve Speed Warning

The normal operating mode involves a vehicle approaching any curve equipped with a CSW application. In the unequipped vehicle case (DII only), all infrastructure components are operational. The CSW infrastructure application collects real-time information via the infrastructure data equipment. The infrastructure application processes the information and, if necessary, provides a warning to the driver via the intelligent roadside signage. In the equipped vehicle case (DII and DVI), all infrastructure and vehicle components are operational. The CSW infrastructure collects real-time and static information from the infrastructure data equipment and communicates this information to the CSW vehicle application. The CSW vehicle application takes the infrastructure data along with vehicle data system information and computes a safe speed. If necessary, the onboard warning system will transmit a warning to the driver in adequate time to slow down before losing control of the vehicle. The DII will also communicate a warning to the driver to slow down.

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 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 which 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.

Should the application be connected to a traffic operations center, 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 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 continuously. 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, V2I safety applications will continue to the extent possible, 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 any critical infrastructure or vehicle component is off-line the application will not activate. Instead, the DVI will report the off-line status 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 unequipped 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.
- USDOT – responsible for developing high-level guidance to state and local agencies in the deployment and operation of connected vehicle V2I safety applications.
- Vehicle drivers – responsible for the decisions made when approaching and entering an intersection or curve. Drivers are also responsible for the following:
    - 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.

There may be other secondary users (stakeholders) of connected vehicle V2I safety applications.

Automobile OEMs

Automobile OEMs may include this role 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 incorporate their role into 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.

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 backend connectivity from roadside equipment to Traffic Control Centers, 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 incorporate its role into 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.

Vehicle Drivers

Each vehicle driver will experience the connected vehicle V2I safety applications outputs when approaching connected vehicle controlled intersections and curves and 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.[42]

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.

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

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.

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 roadside equipment 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. Interaction between 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 (SAE), 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, road weather information system (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) 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. Operational Scenarios

This chapter will present operational scenarios, which describe how the three 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 RLVW, SSGA, and CSW.

6.1 Red-Light Violation Warning

The RLVW application is intended to alert or warn drivers who are approaching a signalized intersection if they are on a trajectory to violate a red signal. Although the precise timing and algorithm of RLVW-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.

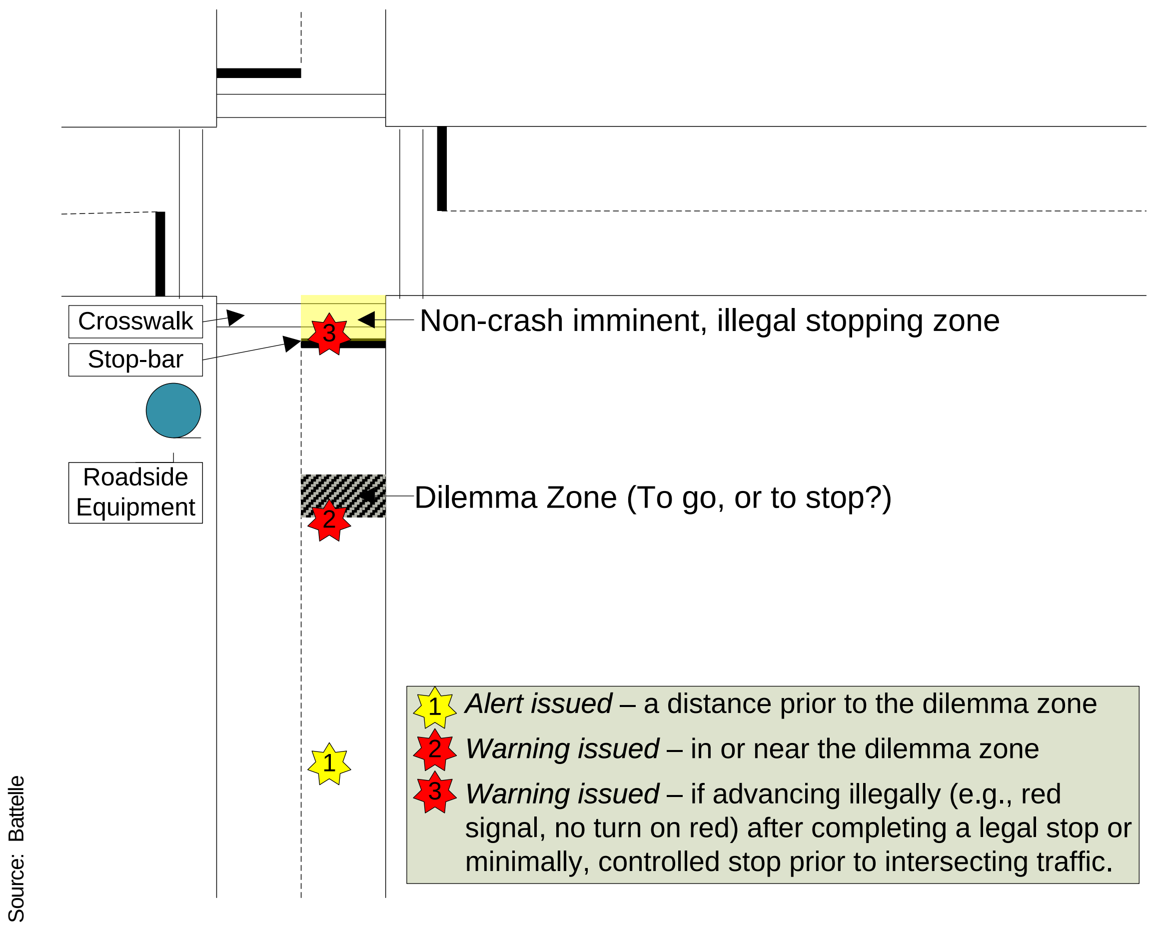


Figure 6-1. RLVW Terminology and Locations

6.1.1 Preconditions and Assumptions

- RLVW-enabled vehicle with an RLVW application platform.
- The vehicle is approaching an RLVW-enabled signalized intersection.
- Information is processed in the vehicle.
- The vehicle will not consider acceleration as an option to “race” through the intersection to avoid stopping for an impending red light.
- An impaired or disabled RLVW signalized intersection (i.e., due to an infrastructure-based system failure or loss of functionality) is either detected by the RLVW enabled vehicle or broadcast by an upstream location as a special message to the vehicle to report this disabled state at the next RLVW enabled intersection. In this case, the RLVW application will be inactive for the intersection (i.e., treat the intersection as a non- RLVW signalized intersection).
- If the vehicle does not receive traffic signal (i.e., SPaT) information or other necessary data, RLVW will be inactive for the intersection.
- If the vehicle positioning information cannot be determined at a lane level, the RLVW application will either[43]:
  - Be inactive for the intersection
  - Assume the traffic signal information for through lanes, unless the turn signal is activated by the driver or onboard navigation system indicates a turn.
- Jurisdictions have different definitions of legal stops at an intersection, i.e., turns on red after rolling or complete stops. Further, it is not unusual for vehicles to 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 are attempting to make a legal turn on red or coming to a stop after the stop bar.
- It is expected that the RLVW application will work in conjunction with other safety applications, which may include intersection movement assist or SLTA; traffic signal adaptation; or providing information, an alert, or warning to cross-traffic about a violation.
- It is expected that situations involving emergency vehicles may require other RLVW-equipped vehicles to enter an RLVW-equipped intersection during a red light phase. In this event, it is expected that a “nuisance” warning would be issued by the RLVW application that the driver would understandably and necessarily disregard (as with the red signal itself).

[43] Appropriate protocols (e.g., perhaps using turn signal activation information or onboard navigation system inputs) will have to be developed for the case in which a warning may be needed but it cannot be determined which of the approach lanes the vehicle will take to pass through the intersection (e.g., prior to formation of the turn lane).

6.1.2 Normal Operating Scenario

An equipped vehicle approaches any RLVW-equipped signalized intersection.

Description of Events/Processes

1. An equipped vehicle approaches an RLVW application enabled intersection and comes in range of the application's roadside communications.
2. The equipped vehicle detects available RLVW data:
   - Intersection geometry information (e.g., GID)
   - Area geospatial information (i.e., GID information for multiple intersections in the area) (optional)
   - Status of the intersection
   - Positioning system corrections (optional)
   - Traffic law restrictions for the intersection (i.e., right- or left-turn on red prohibited, permitted without stopping, or permitted after stopping).
3. 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.
4. The equipped vehicle processes the intersection information:
   a. The RLVW application performs geospatial matching using the positioning correction information to locate itself relative to the intersection at the lane level.
   b. The RLVW application obtains the status of the intersection.
   c. The RLVW application determines the RLVW enabled simple intersection current traffic signal indication for its lane and bearing (i.e., left, through, right) and time remaining in the appropriate phase.
   d. The RLVW 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., the traffic signal is currently or will imminently be red.
      i. The RLVW application makes adjustments for turning vehicles, if applicable, by examining available data (e.g., lane-level information for turn-only lane, turn signal activation, onboard navigation system, traffic law restrictions about permitted or prohibited turns on red). Then:
         1. The RLVW application will adjust the algorithm, if warranted, for permissible rolling turns on red
         2. The RLVW application will grant a warning exemption, if warranted, for permissible turns either after or without stopping.
   e. The RLVW application monitors the vehicle speed for any corrective action (e.g., braking) to determine whether the driver is responding to the signal in a way that will prevent a violation from occurring, issuing an appropriate alert and/or warning, if warranted:
      i. At an appropriate distance from the stop bar (i.e., prior to the dilemma zone, computed as a function of available data using friction factor, vehicle parameters, roadway geometry, vehicle operating conditions, traffic signal state, roadway conditions, perception-reaction time, etc.), the RLVW application and DVI provide a

visual/haptic/audio alert to the driver, if deemed necessary by a deceleration algorithm, that a red or imminent red traffic signal is ahead.

ii. At a second, closer distance to the stop bar, presumed to be in or near the dilemma zone (as defined above):
    1. The RLVW application and DVI provide a more urgent visual/haptic/audio warning to the driver, if deemed necessary by a deceleration algorithm, that a red or imminent red traffic signal is ahead.
    2. 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.

iii. Upon completion of a legal stop or, at a minimum, controlled stop in advance of intersecting traffic, the RLVW application and DVI will issue a visual/haptic/audio warning to drivers advancing illegally (e.g., red signal, no turn on red).

5. After the vehicle has proceeded through the intersection, the RLVW application terminates operations for the intersection.

6.2 Stop Sign Gap Assist

The SSGA application is intended to provide advisory information to minor road drivers at a stop-sign controlled intersection 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. However, to provide context, examples of proposed SSGA intersection layouts are given below. An example proposed divided highway intersection layout, similar to those deployed in Minnesota, is displayed in Figure 6-2. For this scenario, there is an area for minor road vehicles to proceed through the intersection in two steps by pausing after proceeding through gaps in cross-traffic from one direction (i.e., the left), before proceeding through a gap in cross-traffic from the other direction (i.e., the right).

Two levels of driver notification are envisioned for SSGA, 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. Figure 6-3 shows an example of proposed DII signage warnings modeled from MUTCD sign R6-3 or R6-3a showing warnings of approaching vehicles from both directions of a major divided road for minor road vehicles at a SSGA equipped intersection. In the present deployments, this warning is when the gap between the intersection and approaching vehicle is less than or equal to 7 seconds; an alert message is similar there, but with yellow rectangles representing a gap in cross-traffic less than or equal to 11 seconds. The top image of Figure 6-3 shows the DII (Near-Side DII) for drivers crossing the entire intersection. When the driver advances to the median, a second DII (Far-Side DII) on the far side of the intersection, displayed in the bottom image, shows warnings for cross-traffic from the right; note that the bottom part of the bottom sign is faded out to provide spatial context. Again, although a similar layout and DII signage display is currently deployed in Minnesota, the example included here does not prescribe a specific design solution, nor does it prohibit the deployment of alternate intersection layouts for SSGA deployments nor DII signage displays.

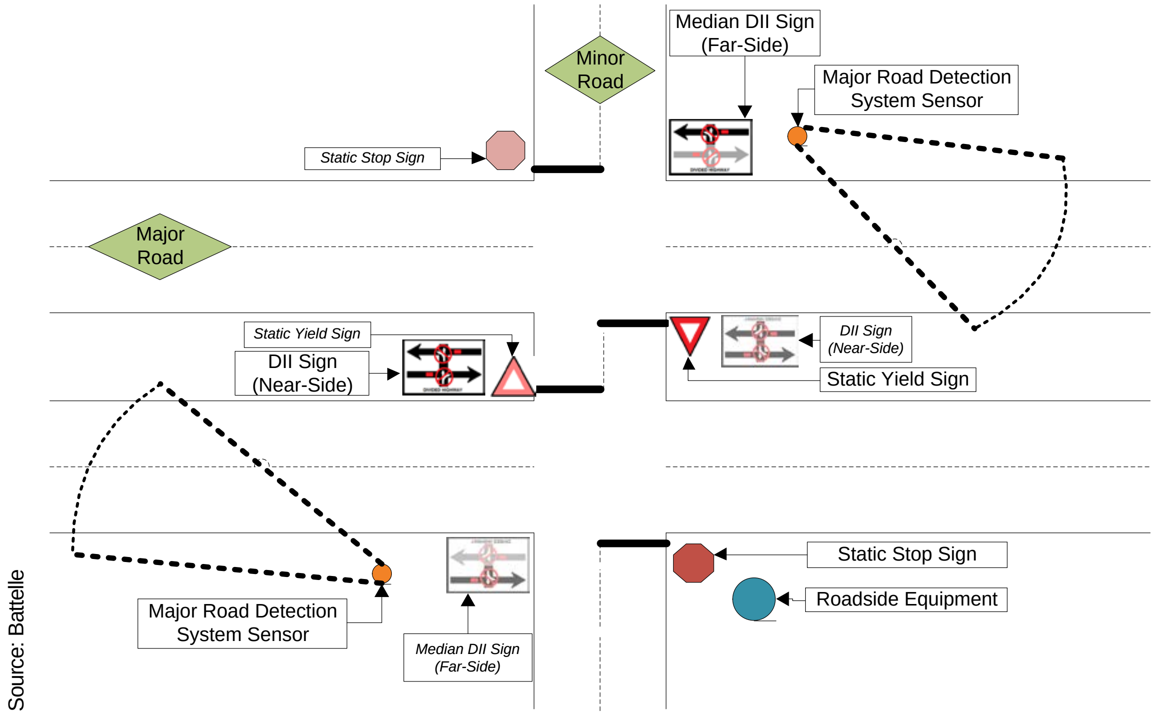
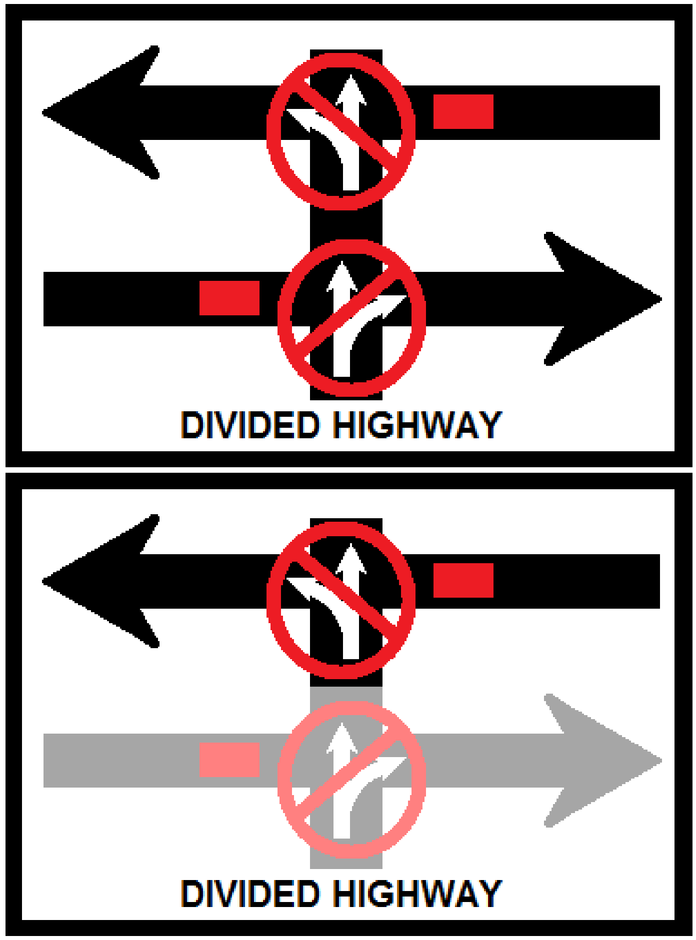


Figure 6-2. Intersection Layout for the SSGA with Median[44]

[44] An example intersection layout for SSGA at an intersection with an area in the median for vehicles to pause, as deployed in Minnesota. (Light-shaded elements with small italicized labels are for vehicles traveling from top to bottom)

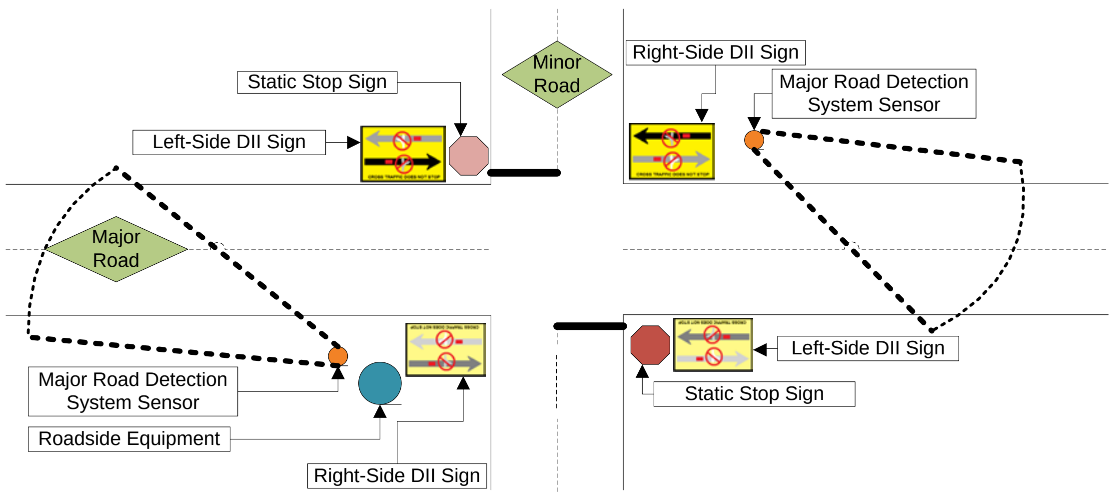


Source: Battelle

Figure 6-3. Example SSGA DII for Minor Road Drivers at a Major Divided Road[45]

[45] A DII message (top) for drivers crossing the entire intersection may differ from a DII message for drivers in the median (bottom); fading out the bottom part of the sign provides spatial context.

A proposed example intersection layout for a non-divided highway is displayed in Figure 6-4. For this scenario, minor road vehicles must proceed through the intersection in only one step. Figure 6-5 shows an example of proposed DII signage warnings for this scenario, modeled on MUTCD "Cross Traffic Does Not Stop" plaque W4-4P and sign R6-3, showing warnings of approaching vehicles from both directions of a major non-divided road for minor road vehicles at an SSGA equipped intersection. The top image shows a possible DII display for the far-right side of the minor road for drivers looking to the right for cross-traffic from the right. Potentially, a second DII (left-side DII) is on the far-left side of the intersection, showing warnings for cross-traffic from the left, displayed in the bottom image. Note that portions of the signs are faded out to provide spatial context to focus driver attention on the warning regarding the direction they are looking to gain information. Again, the reference here does not prohibit the deployment of alternate intersection layouts for SSGA deployments nor DII signage displays.



Source: Battelle

Figure 6-4. Intersection Layout for the SSGA at a Single-maneuver Intersection[46]

[46] Lighter-shaded elements are for vehicles traveling from top to bottom

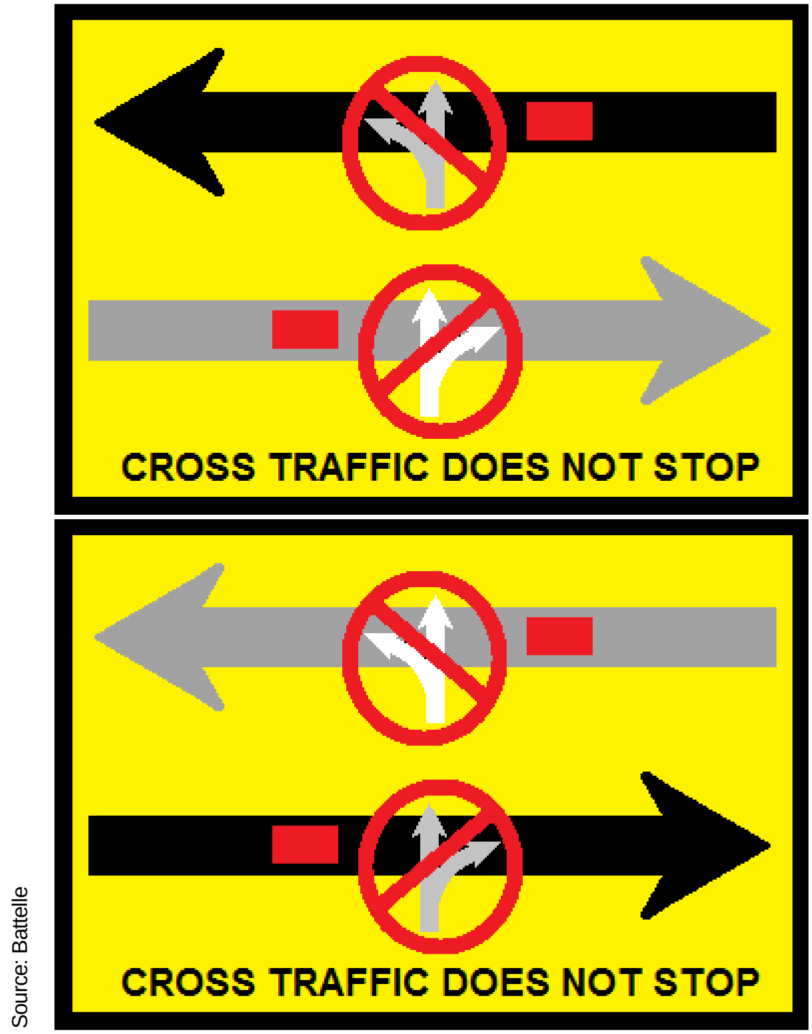


Figure 6-5. Example SSGA DII for Minor Road Drivers at an Undivided Intersection[47]

6.2.1 Preconditions and Assumptions

- Application is working with normal capability such that information is presented on the DII.
- Application is programmed to know necessary gap for vehicle on minor road to clear major road.
- Application has capabilities to detect presence, speed, distance from the intersecting road, and acceleration of vehicles on major road.
- The only drivers affected by the SSGA application are those stopped at the intersection with the intent to either enter or cross the major road traffic.
- The DII is designed such that a driver on the minor road is aware if the application is inactive.

[47] A DII message to drivers looking to the right for cross-traffic (top) might differ from a DII message for drivers looking to the left for cross-traffic (bottom); faded parts of the signs provide spatial context.

- A prohibitive reference frame (i.e., indicating to a driver when not safe to go) is used to lessen liability issues as compared to indicating to a driver when it is "safe" to go; "unsafe" is much easier to quantify than is safe.
- In the event of failure of any vital component, e.g., major road sensors, the SSGA application will not activate, and the DII will enter a "do no harm" fail-safe mode, the DVI will remain inactive, and drivers will rely on static signage.
- DVI will remain inactive for a non-SSGA equipped intersection.
- The SSGA application might be used in conjunction with other connected vehicle applications, including stop sign violation warning (SSVW), which would require sensing on the minor road, and would provide information to major road vehicles via either DII or DVI of vehicles entering or crossing the major roadway.
- For the foreseeable future, DII signage will be required at intersections to assist all minor road vehicles. A DVI-only scenario is not likely in the short term until a sufficient percentage of vehicles are equipped with a DVI to receive alerts or warnings.

6.2.2 Normal Scenario for Non-equipped Vehicles (DII only) – no median

The scenario below is described from the standpoint of an initial infrastructure-based deployment with DII signage where there is no room in the middle of the intersection to pause (i.e., no median), and a driver must clear the intersection in only one step. This is an operational scenario that may occur in the near term, in which a non-equipped vehicle approaches a one- or two-way stop-sign controlled intersection. Data are processed on the roadside and the appropriate message is communicated to and displayed on the DII signage. This may be accomplished in a number of ways: on a single DII sign under the stop sign, on a single DII sign on the far side of the intersection, on a set of two DII signs on the far side of the intersection on the left and right, as depicted in Figure 6-4, or in some other fashion to be determined. Again, the precise intersection layout and design of the sign display are still to be determined.

Description of Events/Processes

1. The RSE detects and monitors all vehicles on the major road in either direction (repeated cycle with step 2).
2. The application processes the information on the roadside and displays an appropriate status/alert/warning on the DII signage. Information is not necessarily given regarding oncoming traffic on the minor road.
    a. If no major road vehicles are detected, a standard image is shown on the DII Sign to indicate the application is active (e.g., MUTCD "Cross Traffic Does Not Stop" sign WP-4P).
    b. When unsafe conditions are detected, an appropriate alert or warning is displayed on the DII Signage showing the direction(s) of an oncoming vehicle conflict.
        i. An appropriate alert will be given for cross-traffic nearing the intersection (e.g., an 11-second gap).
        ii. An appropriate warning will be given for imminent cross-traffic (e.g., a 7-second gap). An example display is shown in Figure 6-5.

6.2.3 Normal Scenario for Non-equipped Vehicles (DII only) – with median

The scenario below is described from the standpoint of an initial infrastructure-based deployment with DII signage where there is a median. For this scenario, a median is defined as any space where a driver can pause in the middle of the intersection, to cross the intersection in two steps based on gaps first from the left, and then from the right. This is a similar operational scenario to one that is currently operational and most likely to continue to occur in the near term, in which a non-equipped vehicle approaches a one- or two-way stop-sign controlled intersection. Data are processed on the roadside and the appropriate message is communicated to and displayed on the DII signage. This may be accomplished in a number of ways: on DII signs under the stop sign on the near side and yield sign in the median, on a single DII sign on the far side of the intersection, on a set of two DII signs on the far side right and near side left of the intersection, as depicted in Figure 6-2, or in some other fashion to be determined. Again, the precise intersection layout and design of the sign display are still to be determined.

<u>Description of Events/Processes</u>

1. The RSE detects and tracks all vehicles on the major road in either direction (repeated cycle with steps 2 and 3).
2. The application processes the information on the roadside and displays the appropriate status/alert/warning on the DII signage, at a minimum regarding gaps in cross-traffic from the left. Information is not necessarily given regarding oncoming traffic on the minor road.
    a. If no major road vehicles are detected, an image is shown on the DII sign that will indicate the application is active (e.g., MUTCD “Divided Highway” sign R6-3 or R6-3a).
    b. When unsafe conditions are detected, an appropriate alert or warning is displayed on the DII signage showing the direction(s) of an oncoming vehicle conflict:
        i. An appropriate alert may be shown for cross-traffic nearing the intersection (e.g., an 11-second gap)
        ii. An appropriate warning may be shown for imminent cross-traffic (e.g., a 7-second gap, as shown in the top image of Figure 6-2).
3. When the vehicle advances to the median, only information on gaps in cross-traffic from the right is needed. The application continues to process the information on the roadside and displays appropriate status/alert/warning for vehicles in the median. This may be accomplished by a second DII sign (Far-Side DII Sign) about gaps in traffic from the right. Information is not necessarily presented regarding oncoming traffic on the minor road.
    a. If no major road vehicles are detected, an image is shown on the DII sign that will indicate the application is active (e.g., MUTCD “Divided Highway” sign R6-3 or R6-3a)
    b. When unsafe conditions are detected, an appropriate alert or warning is displayed on the DII Sign:
        i. An appropriate alert may be shown for cross-traffic approaching the intersection (e.g., an 11-second gap)
        ii. An appropriate warning may be shown for imminent cross-traffic (e.g., a 7-second gap, as shown in the bottom image of Figure 6-2).

6.2.4 Normal Scenario for Equipped Vehicles (DII and DVI) – no median

For this scenario, an equipped vehicle approaches a one- or two-way stop-sign controlled intersection without a median, i.e., there is no room in the middle of the intersection to pause, and a driver must clear the intersection in only one step. The scenario below is described from the standpoint of a more mature infrastructure-based deployment with DII signage and vehicles equipped with a DVI and OBE, which is an operational scenario that is likely to develop over the longer term. Although this scenario is described for equipped vehicles, DII signage is still present in the scenario because of the likelihood of a mixed environment in which not all vehicles will be equipped. A DVI may consist of one or two displays (which may simply duplicate messages shown on the DII); audio; and/or haptic messages. With both roadside and OBE capable of processing information in this scenario, the warning/status/alert is computed at the roadside and then communicated to the DII sign and DVI; vehicle-specific data may be processed on the vehicle, or transmitted to the roadside for the RSE to process, and issue a more detailed, specific DVI message. The DII signage display is communicated to the vehicle because, although the DVI may show different or more specific, detailed message, it must be consistent with the DII. For instance, a DII might simply indicate to slow down, where a DII might indicate a specific maximum speed. Because an inactive DII sign might cause drivers in non-equipped vehicles following equipped vehicles to question the functionality of the DII sign, the DII sign supplements DVI warnings and is always expected to be active. Thus, the DVI messages must be developed to be consistent with DII signage messages for this scenario.

Description of Events/Processes

1. A minor road vehicle approaches an SSGA application enabled intersection and comes in range of the application's roadside communications.
2. The OBE activates the onboard SSGA application and DVI.
3. Minor road vehicle detects availability of and receives SSGA data (i.e., at a minimum intersection GID, which includes position of DIIs relative to the vehicle for determination of appropriate warning to display on the DVI).
4. Option: The SSGA-equipped vehicle sends a message to the RSE. The vehicle may broadcast relevant parameters to the RSE, which could include preferred alert and warning timing, vehicle mass, length, and classification, performance capabilities, etc.[48] The RSE could utilize that information to optimize and transmit DVI alert and warning timing information for that equipped vehicle.
5. The major road vehicle detection system detects and tracks all vehicles on major road in either direction (repeated cycle with step 6).
6. Equipped vehicles on the major road broadcast their location information to the RSE to supplement the roadside detection system information. The RSE processes data from the major road vehicle detection system and the appropriate information is communicated to the DII sign and DVI:
    a. The DII sign constantly displays the appropriate status/alert/warning:
        i. If no major road vehicles are detected, an image is shown on the DII sign to indicate the application is active (e.g., MUTCD "Divided Highway" sign R6-3 or R6-3a).

[48] Even if all of this data are capable of being transmitted, to preserve bandwidth and minimize time for data transfer, only relevant data will be included. University of Minnesota studies have shown that not all of this information is relevant for gap selection. Macroscopic Review of Driver Gap Acceptance and Rejection Behavior at Rural Thru-Stop Intersections in the US – Data Collection Results in Eight States: CICAS-SSA, Report #3 (2010).

   ii. When unsafe conditions are detected, an appropriate alert or warning is displayed on the DII sign (e.g., an alert may be shown for ≤11-second gap, and a warning, such as the top image of Figure 6-2, may be shown for ≤7-second gap).

   b. The RSE communicates appropriate information, including DII signage displays, to the vehicle:
      i. The vehicle application processor accepts the information.
      ii. The vehicle application processor processes information, as necessary, to determine the appropriate audio/visual/haptic alert or warning to issue. The DVI will present information that is consistent with the DII signage.

7. Option: OBE in the minor road vehicle announces to RSE that it has left the intersection.
8. Onboard SSGA application is deactivated.

6.2.5 Normal Scenario for Equipped Vehicles (DII and DVI) – with median

For this scenario, an equipped vehicle approaches a one- or two-way stop-sign controlled intersection with a median. The scenario below is similarly described from the standpoint of a more mature infrastructure-based deployment with DII signage and vehicles equipped with a DVI and OBE, which is an operational scenario that is likely to develop over the longer term. Although this scenario is described for equipped vehicles, DII signage is still present in the scenario because of the likelihood of a mixed environment in which not all vehicles will be equipped. A DVI may consist of one or two displays (which may simply duplicate messages shown on the DII), audio, and/or haptic messages. For this scenario, a median is defined as any space where a driver can pause in the middle of the intersection, to cross the intersection in two steps based on gaps first from the left, and then from the right. With both roadside and OBE capable of processing information in this scenario, the warning/status/alert is computed at the roadside and then communicated to the DII sign and DVI; vehicle-specific data may be transmitted to the roadside for the roadside to process and issue a more detailed, specific DVI message. Because an inactive DII sign might cause drivers in non-equipped vehicles following equipped vehicles to question the functionality of the DII sign, the DII sign supplements DVI warnings and is always active. Thus, the DVI message must be consistent with the DII signage.

Description of Events/Processes

1. A minor road vehicle approaches an SSGA application enabled intersection and comes in range of the application's roadside communications.
2. The OBE activates the onboard SSGA application and DVI.
3. Minor road vehicle detects availability of and receives SSGA data (i.e., at a minimum intersection GID, which includes position of DIIs relative to the vehicle for determination of appropriate warning to display on the DVI).
4. Option: The SSGA-equipped vehicle sends a message to the RSE. The vehicle may broadcast relevant parameters to the RSE, which could include preferred alert and warning timing, vehicle mass, length, and classification, performance capabilities, etc.[49] The RSE could utilize that information to optimize and transmit DVI alert and warning timing information for that equipped vehicle.

[49] Even if all of this data are capable of being transmitted, to preserve bandwidth and minimize time for data transfer only relevant data will be included. University of Minnesota studies have shown that not all of this information is relevant for gap selection.

5. The major road vehicle detection system detects and tracks all vehicles on major road in either direction (repeated cycle with steps 6 and 7).
6. Equipped vehicles on the major road broadcast their location information to the RSE to enhance the detection system information. The RSE processes data from the major road vehicle detection system and the appropriate information is communicated to the DII sign and DVI, at a minimum regarding gaps in cross-traffic from the left; information is not necessarily given regarding oncoming traffic on the minor road.
    a. The DII sign constantly displays the appropriate status/alert/warning:
        i. If no major road vehicles are detected, an image is shown on the DII sign to indicate the application is active (e.g., MUTCD “Divided Highway” sign R6-3 or R6-3a).
        ii. When unsafe conditions are detected, an appropriate alert or warning is displayed on the DII Sign (e.g., an alert may be shown for ≤11-second gap, and a warning, such as the top image of Figure 6-2, may be shown for ≤7-second gap).
    b. The RSE communicates appropriate information, including DII signage displays, to the vehicle:
        i. The vehicle application processor accepts the information.
        ii. The vehicle application processor processes information, as necessary, to determine the appropriate audio/visual/haptic alert or warning to issue. The DVI will present information that is consistent with the DII signage.
7. As the vehicle advances to the median, only information on gaps in cross-traffic from the right is needed. The application continues to process information on the roadside and provide appropriate warnings.
    a. Option: The vehicle sends a message to the RSE regarding its presence in the median. The vehicle broadcasts relevant parameters to the RSE, which could include preferred alert and warning timing, vehicle mass, length, and classification, performance capabilities, etc. The RSE may utilize that information to optimize and transmit the DVI alert/warning timing information for that equipped vehicle.
    b. The RSE continues to process data from the major road vehicle detection system and communicates the appropriate information to the far side DII sign and DVI:
        i. The far side DII sign constantly displays the appropriate status/alert/warning:
            1. If no major road vehicles are detected, an image is shown on the DII sign to indicate the application is active (e.g., MUTCD “Divided Highway” sign R6-3 or R6-3a).
            2. When unsafe conditions are detected, an appropriate alert or warning is displayed on the DII Sign (e.g., an alert may be shown for ≤11-second gap, and a warning, such as the bottom image of Figure 6-2, may be shown for ≤7-second gap).
        ii. The RSE communicates information, including DII signage displays, to the vehicle. No information is necessarily given regarding oncoming traffic:
            1. The vehicle application processor accepts the information.
            2. The vehicle application processor processes information, as necessary, to determine the appropriate audio/visual/haptic alert or warning to issue. The DVI will present information that is consistent with the DII signage.
8. Option: OBE in the minor road vehicle announces to RSE that it has left the intersection.
9. Onboard SSGA application is deactivated.

6.3 Curve Speed Warning

The CSW safety application is intended to improve safety around curves on a stretch of road through the use of vehicle-based and infrastructure-based technologies to help drivers approaching a curve travel through the curve(s) at a safe speed using curve geometry, real-time road and weather conditions, vehicle telematics data, and vehicle configuration data. In particular, the application is intended to warn drivers if they are exceeding the safe speed threshold, which may result in a loss of vehicle stability leading to ROR or rollover events.

6.3.1 Preconditions and Assumptions

- The vehicle is driving along a route equipped with a CSW application.
- The vehicle is en route to a destination requiring it to traverse a stretch of roadway with curve(s). This stretch of roadway may be part of the roadway design and unavoidable, or it may be part of a roadway that diverges into different paths, in which the driver selects the non-primary pathway (e.g., an exit ramp, a fork in a two-lane rural road).
    - The application is working with normal capability such that information is presented on the DII.
    - A prohibitive reference frame (i.e., indicating to a driver when to slow down) is used to lessen liability issues as compared to indicating to a driver when he or she is driving at a safe speed. “Unsafe” is much easier to quantify than safe.
    - The DVI will remain inactive for all non-CSW stretches of roadway.
    - In the case of an equipped vehicle, DVI messages will always be consistent with the DII signage.
    - The CSW application might be used in conjunction with other connected vehicle applications.
- In the case of an equipped vehicle, if any data element is unavailable for calculating an appropriate speed, a previously determined default value will be used by the application to compute a safe speed.
- In the case of an equipped vehicle, the DVI will be effective and compatible with automotive human factors guidelines, OEM DVI principles and practices, and DVIs that follow human factor guidelines by the FHWA, NHTSA, and SAE.
- In the event of failure of any vital component, the CSW application will not activate, and the DVI interface will report the off-line status of the system. The driver is expected to utilize DII to make an educated decision on a safe vehicle speed.

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 stretch of road with curve(s). 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 stretch of road which is equipped with CSW infrastructure, including intelligent roadside signage. 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 stretch of road for which a CSW application exists.
   - The application, including the DII signage, is placed ahead of the roadway in such a way that the vehicle receives the roadway warning in enough time for a driver to reduce speed, if necessary.
2. The CSW infrastructure application receives real-time information from the infrastructure data equipment.
   - At a minimum, information shall include the current vehicle speed. If available and applicable, it may include road and weather conditions and visibility levels.
3. The CSW infrastructure application determines whether a warning is necessary.
   - The infrastructure application runs an algorithm based on the data received.
4. If necessary, a warning is issued to the driver.
   - The CSW infrastructure application provides a message via the roadside signage. The message displayed will not provide a recommended speed but rather a warning to reduce vehicle speed. This message may be variable. For example, messages might say something such as "Curve Ahead/Reduce Speed" and may include road and weather conditions such as "Snowy Conditions/Curve Ahead/Reduce Speed."

6.3.3 Normal Scenario for Equipped Vehicles (DII and DVI)

For this scenario, an equipped vehicle approaches a stretch of road with curve(s). The scenario below is similarly 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. DVI messages must always be consistent with the DII signage.

Description of Events/Processes:

1. The equipped vehicle approaches a stretch of road for which a CSW application exists.
2. The vehicle receives information from the CSW infrastructure application. The vehicle stores this information in its CSW vehicle application.
   - Transmitted information shall include at a minimum curve radius, roadway superelevation, slope, roadway material, and posted curve speed limit. If available, information may also include road and weather conditions and visibility limitations (fog, rain, snow).
   - Curve 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.

3. The vehicle retrieves information from its vehicle data systems.
   - This information may include vehicle speed and rate of acceleration, steering wheel angle, turn signal activation, and interventions by the ESC, ABS, or traction control, as applicable. The system information also includes vehicle telematics and configuration parameters.
4. The CSW vehicle application processes the infrastructure and vehicle information.
   - The application runs an algorithm to identify an appropriate speed to navigate the curve. The algorithm takes into account factors related to loss of vehicle control, which may include curve geometry, road and weather conditions, vehicle speed and acceleration, vehicle telematics, and vehicle configuration data.
5. The CSW vehicle application determines if the current operating speed exceeds the calculated safe speed for approaching the curved stretch of roadway.
6. As necessary, a warning is issued to the driver.
   - The onboard warning system will warn the driver in sufficient time to reduce speed to safely navigate the curve. The warning may be aural, visual, and/or haptic.
   - The DII signage will also illuminate a warning message. The message displayed will not provide a recommended speed but rather a warning to reduce vehicle speed. This message may be variable. For example, messages might say something such as “Curve Ahead/Reduce Speed” and may include road and weather conditions such as “Snowy Conditions/Curve Ahead/Reduce Speed.”
   - Option: If the curve is part of a divergent path selected by the driver, the CSW vehicle application will warn the driver once the application determines that the driver is committed to taking the curve.

7. Summary of Impacts

Implementation of these V2I safety applications: RLVW, SSGA, and CSW 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 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 unequipped 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 biggest impact is that drivers will receive real-time warnings while driving based on their current driving conditions. Warnings include: CSW, warning of a red or imminent red light at a signalized intersection

(RLVW), and warnings for unsafe conditions for proceeding from a minor road through a stop-sign controlled intersection (SSGA). This information should result in safer trips with fewer incidents on roadway curves and at intersections, both signalized and non-non-signalized. 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 proceed around a curve (CSW), reduce speed to stop at a red or imminent red light (RLVW), or prevent a driver from proceeding into an intersection with oncoming traffic (SSGA). 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. For example, drivers could misuse RLVW warnings to accelerate and speed through an intersection with an impending red light rather than safely stop. Likewise, over-reliance on SSGA might discourage drivers from visually verifying a safe gap at an intersection, as is intended. These examples of modified behaviors would compromise the safety benefits expected from these applications.

7.1.2 State and Local Government/DOT Impacts

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. 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. 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: RLVW, SSGA, and CSW.

8.1 Summary of Improvements

The three connected vehicle V2I safety applications will provide new capabilities for detecting and warning motorists about potential unsafe conditions at intersections and curves. Through these connected vehicle applications, equipped vehicles and the roadside infrastructure can share information in real time that will help drivers to more safely negotiate roadways. The applications will also increase situational awareness for drivers.

All three applications provide improvements from the current unequipped driving environment:

- **Red Light Violation Warning:** RLVW aids drivers by warning a driver of a red or impending red light at a signalized intersection prior to the point where the vehicle would be unable to safely stop for the red light (i.e., prior to entering the dilemma zone). 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 traffic signal turns yellow and a driver suddenly 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 that warn a driver to “Prepare to Stop When Flashing,” RLVW will provide on onboard warning to the driver based on any data available, including current vehicle operating conditions and roadway conditions.

  The RLVW application also includes the capability of capturing specific intersection geometries in real time via roadside equipment. This, in tandem with positioning capabilities, allows for lane-specific system awareness to help determine intended direction through the intersection (i.e., straight, turn left, or turn right). The application is dynamic and can consider any data available for current road and weather conditions along with other available vehicle telematic 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 traffic signal. 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.

- **Stop Sign Gap Assist:** SSGA aids drivers by warning a driver on a secondary/minor road when it is unsafe to proceed through a stop-controlled intersection. The system detects vehicles on the major, intersecting roadway and issues warning when there is an insufficient gap for safe passage through an intersection. The application is functional for all varieties of intersections: divided or undivided roadways, skewed intersections, etc.

This application incorporates onboard and roadside processing equipment, as well as a dynamic DVI for onboard warnings and DII with automated signage. The automated DII signs will provide warnings of unsafe gaps to drivers of both equipped and non-equipped vehicles. In this way, the application can provide immediate benefits for all drivers at stop-controlled intersections.

- **Curve Speed Warning:** CSW aids drivers by preventing a single vehicle from speeding around a curve and potentially losing vehicle stability. CSW reduces the risk of both run- off-road or vehicle roll-over incidents due to excessive curve speed. Unlike current CSW applications, which largely provide a standard static warning based on radar-detected speeds via the roadside infrastructure, the connected vehicle application provides a real-time warning based on the driver's current driving conditions, unique to the driver and his or her vehicle.

  The V2I CSW application also includes the capability of capturing specific curve geometries and road conditions in real time via roadside equipment. This allows for the real-time calculation of a safe curve speed, based upon current road and weather conditions along with other vehicle telematic data to calculate a more accurate safe speed. The application is also capable of providing a warning within sufficient time for the driver to receive and react to it. The application is designed to remain silent and inactive when the driver's speed is below a threshold; this is to avoid nuisance alerts and increase user acceptance and application effectiveness. The CSW application is functional for all types of curves, whether the curve is part of the roadway design or whether the road diverges into different paths and the driver selects the curved pathway (e.g., exit ramp).

In addition to the specific benefits discussed above, benefits common to all three 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 and invasion breaches.

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 unequipped 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 CSW capabilities is driving along a roadway with a static roadside curve warning sign, the driver may be driving slower than the advisory speed displayed on the static sign. However, due to the real-time calculations that the V2I 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 applications are more accurate, to drivers this may provide confusing messages and reduce the potential safety impact.

Currently the application design is set up in such a way that warning decisions are made by the vehicle (with the exception of SSGA, which includes roadside processing equipment and roadside signage for non-equipped vehicles). 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.

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 warning decisions for RLVW and CSW 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 unequipped 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.

- **RLVW System Considerations:**
  - Red-light running cameras and technology are relatively common, and the use of this equipment for this application has been considered. However, due to the specific nature of the equipment and the timing constraints and placement of the existing technology, it is unlikely that it could be useful for this V2I application due to.
  - The RLVW system is currently intended only to provide a warning to equipped vehicles of a potential violation. The system 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) or change the signal timing (e.g., extend the all-red phase). These are all potential options for consideration a future case scenario.
  - Other safety applications may be active at an intersection, and the RLVW system is intended to accommodate other applications, such as intersection movement assist or SLTA and traffic signal adaptation. Similarly, the RLVW system does not include warnings to cross-traffic of a vehicle violating the red light.

- **SSGA System Considerations:**
  - Because of successful deployments of the CICAS-SSA, which this V2I application is based on, and extensive research regarding the design of roadside infrastructure and signage, this application is intended to provide warnings to both equipped and non-equipped vehicles (as opposed to solely equipped vehicles like the other V2I safety applications presented). This provides an added consideration for vehicles that are not equipped with connected vehicle technology.
  - The SSGA application is intended to be functional for all intersections; intersections with and without a median are considered.
  - The SSGA application is intended to provide a prohibitive frame of reference for gap decisions. The system does not instruct the driver when it is safe to proceed through the intersection, only when there are unsafe conditions.
  - The system does not warn the driver of the stop sign, but instead assumes the driver will stop at the intersection before any message is broadcast to the driver.
  - The SSGA application does not provide warnings to cross-traffic on the major road of minor road traffic crossing or entering the major road. This function could be provided in a separate safety application.

- **CSW System Considerations:**
  - The CSW system is intended to warn the equipped vehicle only about imminent curve-related dangers. The system does not account for other drivers on the roadway or their driving behavior.

9. Notes

9.1 Acronyms and Abbreviations

AAHSTO	American Association of State Highway and Transportation Officials
AAMVA	American Association of Motor Vehicle Administrators
ABS	Anti-Lock Braking System
ATC	Advanced Transportation Signal Controller
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CICAS	Cooperative Intersection Collision Avoidance Systems
CICAS-SSA	Cooperative Intersection Collision Avoidance System-Stop Sign Assist
CICAS-V	Cooperative Intersection Collision Avoidance System Violations
ConOps	Concept of Operations
CSAH	County State Aid Highway
CSW	Curve Speed Warning
DII	Driver-Infrastructure Interface
DMS	Dynamic Message Sign
DOTs	Departments of Transportation
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EBS	Electronic Braking System
ESS	Environmental Sensor Station
ECUs	Electronic Control Units
ESC	Electronic Stability Control
FARS	Fatality Analysis Reporting System
FCW	Forward Collision Warning
FHWA	Federal Highway Administration
FISMA	Federal Information Security Management Act
FOT	Field Operational Test
GID	Geometric Intersection Design
GPS	Global Positioning System
ICWS	Intersection Conflict Warning Systems
ID	Intersection’s Identification
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
IVBSS	Integrated Vehicle-Based Safety System(s)
IVI	Intelligent Vehicle Initiative
JPO	Joint Program Office

LCW	Lane Change Warning
LDW	Lane Departure Warning
LOS	Level of Service
Mn/DOT	Minnesota Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NEMA	National Electrical Manufacturers Association
NTHSA	National Highway Traffic Safety Administration
OBD2	On Board Data II
OBE	Onboard Equipment
OEMs	Original Equipment Manufacturers
QPLs	Qualified Parts Lists
RITA	Research and Innovative Technology Administration
RLVW	Red-Light Violation Warning
ROR	Run-off-Road
RPM	Revolutions Per Minute
RSE	Roadside Equipment
RWIS	Road Weather Information System
SAD	System Architecture Document
SAE	Society of Automotive Engineers
SDLC	Synchronous Data Link Control
SEMP	Systems Engineering Management Plan
SLTA	Signalized Left-Turn Assist
SOI	System of Interest
SPaT	Signal Phase and Timing
SSGA	Stop Sign Gap Assist
SSVW	Stop Sign Violation Warning
SUVs	Sports Utility Vehicles
TEA-21	Transportation Equity Act for the 21st Century
TRB	Transportation Research Board
TSC	Traffic Signal Controller
UMN	University of Minnesota
UMTRI	University of Michigan Transportation Research Institute
USDOT	United States Department of Transportation
V	Vehicle Speed
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
Vc	Maximum Safe Curve Speed
VII	Vehicle Infrastructure Integration
VSC2	Vehicle Safety Communications 2
VTTI	Virginia Tech Transportation Institute

9.2 Terms and Definitions

Alert – a cautionary message about an anticipated crash scenario and/or vehicle conflict.

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.

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.[50] 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.

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.[51]

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.[52]

Warning – a more urgent message for a more immediate, potentially crash imminent scenario and/or vehicle conflict.

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

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

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

Appendix A: Engineering Reference Formulas for Curve Speed Warning

The following formulas may be considered when developing the onboard algorithm to determine the maximum safe speed threshold around a curve.

Maximum safe design speed of a curve: 53, 54

$$V_c = \sqrt{gR\frac{e+f}{1-ef}} \qquad \text{(A-1)}$$

Where:

V_c	=	the maximum safe speed in a curve
g	=	the gravitational acceleration constant
R	=	the radius of the curve
e	=	the superelevation of the curve
f	=	the side friction factor of the pavement and tires

Note: U.S. guidelines for highway design call for a maximum lateral acceleration of no more than 0.17g at most speeds. This value is lower than the lateral accelerations that may be sustained by tires on paved road surfaces in both dry and in most wet conditions.[55] The low value is used for design to allow for the possibility of ice on the surface. Even if the road is capable of providing a higher side friction factor, persons in the vehicle may experience the discomfort associated with high side forces, and a vehicle with a high center of gravity may be subject to roll over.[56]

Note: The f value used to calculate the maximum safe curve speed will vary based on vehicle, road, and weather conditions. The f value used should be substantially less than the coefficient of friction at impending skid. The side friction factor at impending skid will depend on a number of factors, among which the most important are speed of the vehicle, type and condition of the roadway surface, and type and condition of the vehicle tires.

[53] Policy on Geometric Design of Highways and Streets (6th Edition), 2001, AASHTO

[54] Run-Off Road Collision Avoidance Using IVHS Countermeasures Task 4 – Volume 1 – DRAFT, USDOT, September 5, 1995

[55] Road Departure Crash Warning System Field Operational Test: Methodology and Results. Volume 1: Technical Report. UMTRI. June 2006.

[56] Run-Off Road Collision Avoidance Using IVHS Countermeasures Task 4 – Volume 1 – DRAFT, USDOT, September 5, 1995.

While these factors will have to be developed for other vehicles, e.g., passenger car, bus, suggested values for the side friction factor include (by vehicle type):

- Normal Operating Conditions
  - SUVs: ($f = 0.4$)
  - Sedans: ($f = 0.5$)
  - Heavy Duty Trucks: ($f = 0.2$)
- Heavy Rain
  - SUVs: ($f_{max} = 0.2$)
  - Sedans: ($f_{max} = 0.2$)
  - Heavy Duty Trucks: ($f_{max} = 0.2$)
- Freezing Conditions
  - SUVs: ($f_{max} = 0.05$)
  - Sedans: ($f_{max} = 0.05$)
  - Heavy Duty Trucks: ($f_{max} = 0.05$)

  Note: When snow and ice are a factor, the rate of superelevation (e) should not exceed the rate at which vehicles standing or traveling slowly would slide toward the center of the curve when the pavement is icy.

Distance to the curve entry at which point the warning should begin (accounting for the driver's reaction time):[57]

$$d = \frac{V^2 - V_c^2}{2a} + t_r V \qquad \text{(A-2)}$$

Where:

d	=	the distance between the current vehicle position and the curve entry
V	=	the maximum permissible speed at distance d from the curve entry
V_c	=	the maximum safe speed of the curve
a	=	the assumed constant deceleration to reach the curve, and
t_r	=	the reaction time due to countermeasure system and driver reaction delays

[57] Run-Off Road Collision Avoidance Using IVHS Countermeasures Task 4 – Volume 1 – DRAFT, USDOT, September 5, 1995.

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