Vehicle-to-Infrastructure (V2I) Safety Applications

Performance Requirements, Vol. 1, Introduction and Common Requirements

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Final Report — August 2015
FHWA-JPO-16-248

U.S. Department of Transportation

Produced by Battelle Memorial Institute under DTFH61-12-D-00040
U.S. Department of Transportation
Federal Highway Administration Office of Safety Research and Development

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-16-248		

4. Title and Subtitle	5. Report Date
Vehicle-to-Infrastructure (V2I) Safety Applications Performance Requirements, Vol. 1, Introduction and Common Requirements	August 28, 2015
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Denny Stephens, Jeremy Schroeder, Rachel Klein	1000025516-0301

9. Performing Organization Name And Address	10. Work Unit No. (TRAIS)
Battelle Memorial Institute 505 King Avenue Columbus, OH 43201	**11. Contract or Grant No.** DTFH61-12-D-00040

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation FHWA Office of Safety Research and Development Turner-Fairbank Highway Research Center 6300 Georgetown Pike McLean, VA 22101	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Government Technical Monitor; Gregory Davis, FHWA Office of Safety Research and Development

16. Abstract

This document is the first of a seven volume report that describes performance requirements for connected vehicle vehicle-to-infrastructure (V2I) Safety Applications developed for the U.S. Department of Transportation (U.S. DOT). The applications addressed here include Curve Speed Warning (CSW), Red Light Violation Warning (RLVW), Reduced Speed Zone Warning with Lane Closure (RSZW/LC), Spot Weather Information Warning – Reduced Speed (SWIW-RS), Spot Weather Information Warning – Diversion (SWIW-D), and Stop Sign Gap Assist (SSGA). These safety applications integrate roadside and in-vehicle advisories, alerts and warnings to make the driver aware of hazards in time to take action to prevent a potential crash. Performance requirements are specified for both infrastructure- and vehicle-based components of the applications to ensure that roadside and in-vehicle driver messages are coordinated and consistent. This volume provides an introduction to the six V2I Safety Applications and performance requirements and resource information that are common to all six applications. Performance requirements specific to individual applications are provided in Volumes 2 through 7 of this report.

17. Key Words	18. Distribution Statement
Connected vehicles, Vehicle-to-Infrastructure, V2I, V2I Safety Applications, Curve Speed Warning, Red Light Violation Warning, Reduced Speed Zone Warning with Lane Closure, Spot Weather Information Warning, Stop Sign Gap Assist	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Table of Contents

List of Tables

List of Figures

Executive Summary

Connected vehicle applications offer tremendous promise for major improvements in highway safety and mobility, and for reducing the environmental impact of highway travel. Connected vehicle technologies function within a vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data communications environment that supports numerous public and private applications. The data-rich environment offered by connected vehicle technologies can support a wealth of applications to improve roadway safety and mobility. Connected vehicle technologies are expected to help substantially reduce the 30,000 to 40,000 fatalities experienced each year on our roads and highways based on the Fatality Analysis Reporting System (FARS) statistics. Using high-speed wireless communications between infrastructure and vehicles, connected vehicle applications offer the opportunity to combine data from the infrastructure (e.g., slippery road surface conditions) with data from the vehicle (e.g., speed in a curve) to assess crash likelihood (e.g., run-off-road) resulting in the delivery of more accurate and robust hazard warnings to drivers, thereby reducing the potential for a crash.

This document is the first of seven volumes that describes the Performance Requirements for six connected vehicle vehicle-to-infrastructure (V2I) crash avoidance safety applications developed for the U.S. Department of Transportation (U.S. DOT). The objective of this V2I Safety Application Performance Requirements report is to provide integrated requirements for the infrastructure and vehicle components of a series of V2I safety applications, their wireless messaging and their driver messaging that ensure coordinated and consistent delivery of safety hazard advisories, alerts and warnings to drivers. The safety applications described here capture relevant data from roadside infrastructure sensors and in-vehicle sensors and process them to determine if there is a potential crash hazard. If a hazard is detected, the applications issue integrated roadside and in-vehicle advisories, alerts and warnings to make the driver aware of the hazards in time to take action to prevent the crash.

The applications described here have both an infrastructure-based component and a vehicle-based component, which may be developed by different stakeholders. Infrastructure-based components are expected to be developed by state and local agencies responsible for building and maintaining the roadway infrastructure and their contractors. Vehicle-based components are expected to be developed by vehicle manufacturers, their tier one suppliers, and aftermarket system suppliers. The performance requirements provide requirements for both infrastructure and vehicle application components to ensure the data exchange between the two components is synchronized and consistent and that they deliver messages to the driver that are harmonized to best capture the attention of the driver and that avoid confusing the driver.

The V2I Safety Applications addressed in this report are:

- *Curve Speed Warning (CSW)* – Application designed to advise drivers of an upcoming curve and provide an alert and/or warning when the vehicle's current speed may be too high to safely traverse one or more upcoming curves.
- *Red Light Violation Warning (RLVW)* – Application designed to advise drivers of an upcoming signalized intersection and provide an alert and/or warning when they may

violate an upcoming red light based on their speeds and distance to the signalized intersection.

- *Reduced Speed Zone Warning with Lane Closure (RSZW/LC)* – Application designed to advise drivers of an upcoming reduced speed zone and/or changed roadway configuration, and provide an alert to drivers of excessive speeds compared with the posted speed limit in reduced speed zones and, given lane level accuracy, give an alert and/or warning regarding changed roadway configurations. Reduced speed zones may include school zones, work zones, and populated areas.
- *Spot Weather Information Warning – Reduced Speed (SWIW-RS)* – Application designed to use standalone weather systems to advise drivers about inclement weather conditions (i.e., fog, wind, adverse surface conditions, etc.) that may impact travel conditions and provide an advisory and alert regarding a required reduction in speed through the impacted weather zone.
- *Spot Weather Information Warning – Diversion (SWIW-D)* – Application designed to use standalone weather systems to advise drivers about inclement weather conditions (i.e., fog, wind, adverse surface conditions, etc.) that may impact travel conditions on the roadway ahead and either provide an advisory for a suggested or required diversion in advance of a diversion point, and advisory, alert, and warning message if the vehicle proceeds toward a weather-related road closure.
- *Stop Sign Gap Assist (SSGA)* – Application designed to inform stopped drivers at a stop-controlled intersection of unsafe gaps due to approaching cross-traffic.

The seven volumes comprising this V2I Safety Applications Performance Requirements report are

- Vol. 1, Introduction and Common Requirements
- Vol. 2, Curve Speed Warning (CSW)
- Vol. 3, Red Light Violation Warning (RLVW)
- Vol. 4, Reduced Speed Zone Warning with Lane Closure (RSZW/LC)
- Vol. 5, Spot Weather Information Warning – Reduced Speed (SWIW-RS)
- Vol. 6, Spot Weather Information Warning – Diversion (SWIW-D)
- Vol. 7, Stop Sign Gap Assist (SSGA).

The applications described here were selected for development by the U.S. DOT and state Department of Transportation (DOT) stakeholders because of their potential for improving highway safety. The benefits resulting from deployment of these applications 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.

Chapter 1 Scope

1.1 Document Identification

This document is the first of a seven volume report that describes the performance requirements for six connected vehicle vehicle-to-infrastructure (V2I) safety applications developed for the U.S. Department of Transportation (U.S. DOT). This volume provides 1) an introduction to the six V2I Safety Applications that are described in this report, 2) performance requirements that are common to the infrastructure and vehicle components of all six applications, and 3) appendices and resource information applicable to all applications.

The seven volumes comprising this V2I Safety Applications Performance Requirements report are:

- Vol. 1, Introduction and Common Requirements
- Vol. 2, Curve Speed Warning (CSW)
- Vol. 3, Red Light Violation Warning (RLVW)
- Vol. 4, Reduced Speed Zone Warning with Lane Closure (RSZW/LC)
- Vol. 5, Spot Weather Information Warning – Reduced Speed (SWIW-RS)
- Vol. 6, Spot Weather Information Warning – Diversion (SWIW-D)
- Vol. 7, Stop Sign Gap Assist (SSGA).

These volumes transform the Concept of Operations (ConOps) and system requirements previously developed for these applications into a set of performance requirements which specify how the applications integrate roadside and in-vehicle advisories, alerts and warnings to make the driver aware of hazards in time to take action to prevent a potential crash. Performance requirements are provided for both infrastructure and vehicle application components of the application to ensure that infrastructure and vehicle messages presented to drivers are consistent and coordinated.

1.2 Document Overview

The objective of this V2I Safety Application Performance Requirements report is to provide integrated requirements for the infrastructure and vehicle components of a series of V2I safety applications, their wireless messaging and their driver messaging that ensure coordinated and consistent delivery of safety hazard advisories, alerts and warnings to drivers. This volume describes the V2I System of Systems within which these applications are expected to function.

The safety applications described here capture relevant data from roadside infrastructure sensors and in-vehicle sensors and process them to determine if there is a potential crash hazard. If a hazard is detected, the applications issue integrated roadside and in-vehicle advisories, alerts and warnings to make the driver aware of the hazards in time to take action to prevent the crash.

The applications described here have both an infrastructure-based component and a vehicle-based component, which may be developed by different stakeholders. Infrastructure-based components are expected to be developed by state and local agencies responsible for building and maintaining the roadway infrastructure and their contractors. Vehicle-based components are expected to be developed by vehicle manufacturers, their tier one suppliers, and aftermarket system suppliers. The performance requirements provide requirements for both infrastructure and vehicle application components to ensure the data exchange between the two components is synchronized and consistent and that they deliver messages to the driver that are harmonized to best capture the attention of the driver and that avoid confusing the driver.

This report has been written with the assumption that the reader possesses a general knowledge associated with connected vehicles and the associated infrastructure surrounding connected vehicles.

The intended audience of this report includes infrastructure and vehicle application developers, wireless equipment systems manufacturers, Intelligent Transportation Systems (ITS) developers, state and local departments of transportation (DOTs), and U.S. DOT Connected Vehicle program managers.

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

Section 2 Referenced Documents describes the external documentation utilized and referenced throughout this report.

Section 3 Performance Requirements provides an introduction to and the common requirements applicable to all applications considered here.

Appendices include supplemental information relevant to all applications, including:

- Appendix A: MUTCD Guidance Relevant to Selected Connected Vehicle V2I Safety Applications
- Appendix B: Equations and Resources for Determining Issuance of Alerts and Warnings
- Appendix C: Acronyms and Abbreviations
- Appendix D: Terms and Definitions

1.3 V2I Safety Applications Performance Requirements Project Overview

Connected vehicle applications offer tremendous promise for major improvements in highway safety and mobility, and for reducing the environmental impact of highway travel. Connected vehicle technologies function within a vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data communications environment that supports numerous public and private applications. Using high-speed wireless communications between infrastructure and vehicles, connected vehicle applications offer the opportunity to combine data from the infrastructure (e.g., slippery road surface conditions) with data from the vehicle (e.g., speed in a curve) to assess crash likelihood (e.g., run-off-road) resulting in the delivery of more accurate and robust hazard warnings to drivers, thereby reducing the potential for a crash.

The data-rich environment offered by connected vehicle technologies can support a wealth of applications to improve roadway safety. Connected vehicle technologies are expected to help substantially reduce the 30,000 to 40,000 fatalities experienced each year on our roads and highways based on the Fatality Analysis Reporting System (FARS) statistics.

This project for development of V2I Safety Application Performance Requirements follows the V2I Safety Application Concept of Operations project in which ConOps and system requirements were developed for selected safety applications. The previous project identified high priority applications and developed the underlying principles and architecture for integrating infrastructure and in-vehicle data, processing the data to assess potential hazards, and issuing advisories, alerts and warnings to drivers. The six applications addressed in this report are:

- *Curve Speed Warning (CSW)* – Application designed to advise drivers of an upcoming curve and provide an alert and/or warning when the vehicle's current speed may be too high to safely traverse one or more upcoming curves.
- *Red Light Violation Warning (RLVW)* – Application designed to advise drivers of an upcoming signalized intersection and provide an alert and/or warning when they may violate an upcoming red light based on their speeds and distance to the signalized intersection.
- *Reduced Speed Zone Warning with Lane Closure (RSZW/LC)* – Application designed to advise drivers of an upcoming reduced speed zone and/or changed roadway configuration, and provide an alert to drivers of excessive speeds compared with the posted speed limit in reduced speed zones and, given lane level accuracy, give an alert and/or warning regarding changed roadway configurations. Reduced speed zones may include school zones, work zones, and populated areas.
- *Spot Weather Information Warning – Reduced Speed (SWIW-RS)* – Application designed to use standalone weather systems to advise drivers about inclement weather conditions (i.e., fog, wind, adverse surface conditions, etc.) that may impact travel conditions and provide an advisory and alert regarding a required reduction in speed through the impacted weather zone.
- *Spot Weather Information Warning – Diversion (SWIW-D)* – Application designed to use standalone weather systems to advise drivers about inclement weather conditions (i.e., fog, wind, adverse surface conditions, etc.) that may impact travel conditions on the roadway ahead and either provide an advisory for a suggested or required diversion in advance of a diversion point, and advisory, alert, and warning message if the vehicle proceeds toward a weather-related road closure.
- *Stop Sign Gap Assist (SSGA)* – Application designed to inform stopped drivers at a stop-controlled intersection of unsafe gaps due to approaching cross-traffic.

The results of prior work are described in the following reports[1]:

- Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications Concept of Operations Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-058. (2012).
- Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-059. (2012).
- Vehicle-to-Infrastructure (V2I) Safety Applications Concept of Operations Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-060. (2013).
- Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-061. (2013).

Upon completion of the previous work, it was determined that detailed performance requirements were required for this system to ensure the reliable integration of infrastructure and vehicle data by application components developed by different agencies. It was determined that more detailed guidance is needed for the developers of infrastructure and vehicle components of the applications to ensure that roadside and in-vehicle messages to drivers are consistent and synchronized and that they enhance roadway safety.

In support of this goal, the objective of this project is to develop system engineering performance requirements for V2I safety applications using the systems engineering process outlined in IEEE Standard 1362-1998. Development of these performance requirements is based on existing ConOps and system requirements documents. The resulting performance requirements provide the basis for design documentation and validation of working prototype V2I safety applications, which are described in the section below.

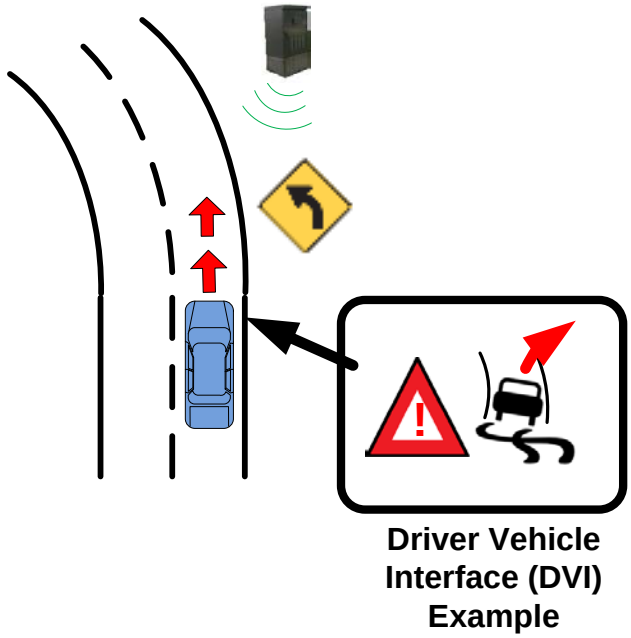
1.4 V2I Safety Applications Overview

This report describes the performance requirements for six connected vehicle V2I safety applications related to intersection and roadway safety. Applications described here may be developed either by retrofitting existing equipment or by deploying new equipment. Some applications may include either fixed or portable infrastructure. Additionally, the nature of some applications will vary by the type of deployment (e.g., the type of inclement weather in an area requires diversion or a reduced speed), while the provision of alerts and warnings will be influenced by the availability of supplemental data and information, and whether or not vehicles are equipped. Following is a more detailed description of each of these applications with explanatory graphics.

Curve Speed Warning – The objective of CSW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding run-off-road crashes by first advising the driver of an upcoming curve, and then providing an alert, followed by a warning to the vehicle driver if 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-based vehicle detection sensors or a combination of multiple types of sensors (e.g., radar and

[1] Note that the Spot Weather Information Warning application described in earlier project is now addressed as two separate applications, SWIW-Reduced Speed and SWIW-Diversion, due to differences in implementation.

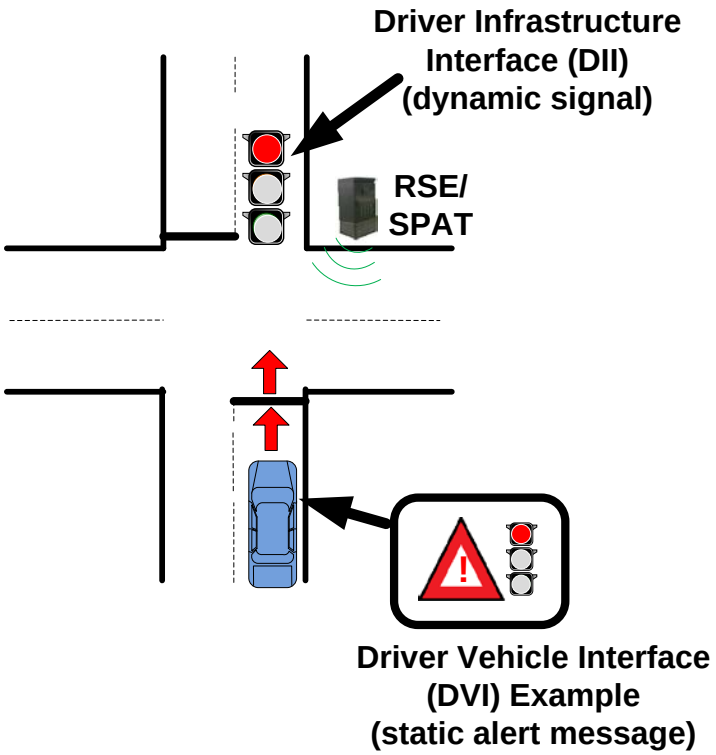
environmental sensors), then process available data to recommend an appropriate advisory message and/or alert to provide messages to drivers via driver-infrastructure interface (DII) signage. An equipped vehicle approaching an equipped curve receives messages from the roadside equipment and will display an appropriate advisory message, alert, and/or warning for the driver on the in-vehicle driver-vehicle interface (DVI). Figure 1-1 illustrates the proposed CSW application concept.



Source: Battelle

Figure 1-1. Illustration of Curve Speed Warning Application Infrastructure and Driver Messaging

Red Light Violation Warning – The objective of RLVW is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes at signalized intersections by first advising the driver of an signalized intersection, and then providing an alert, followed by a warning to the vehicle driver if, 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 an alert and/or warning if the application determines that, given current operating conditions, the driver is predicted to violate the red light. This application does not include any DII advisory, alert, or warning messages aside from already existing traffic signal. Also, this application does not address dilemma zone protection. Figure 1-2 illustrates the proposed RLVW application concept.



Source: Battelle

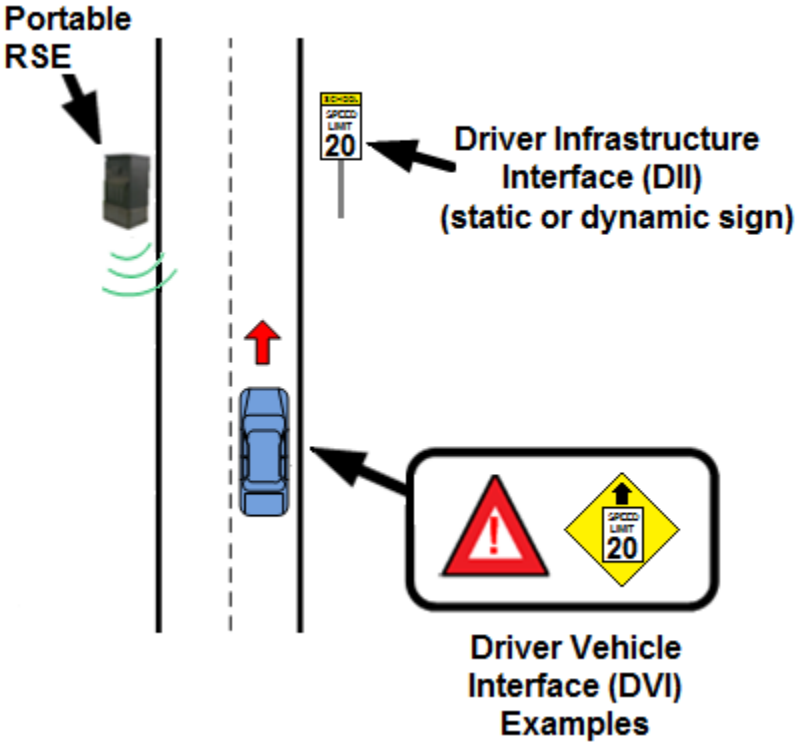
Figure 1-2. Illustration of Red Light Violation Warning Application Infrastructure and Driver Messaging

Reduced Speed Zone Warning with Lane Closure – The objective of the RSZW/LC application is to improve safety in Reduced Speed Zones, such as school zones and work zones, by improving conformance with the speed limit in areas where, for example, school children, pedestrians, and construction workers are at risk from speeding vehicles. The RSZW/LC application coordinates roadside messages and in-vehicle advisories and alerts to notify drivers in time for them to slow to the posted speed limit and maintain a speed at or below the posted speed limit within the Reduced Speed Zone. Where applicable, additional messages are provided for changed roadway configurations, such as a lane closure or lane shift. The application also coordinates roadside and in-vehicle advisories of upcoming roadway configurations. For deployments with both reduced speed and changed roadway configurations, advisory and/or alert messages regarding the need to reduce speed and change lanes will be displayed simultaneously.

An equipped vehicle on a road ahead of a reduced speed zone and/or changes in roadway configuration is first issued an advisory message of reduced speed zone ahead, and, if applicable, a change in roadway configuration. An alert is issued to the driver subsequently if the vehicle application component determines that the vehicle is failing to conform to the reduced speed limit. An alert and a warning are also issued if the driver fails to make a mandatory lane change or maneuver necessary to accommodate changed roadway configurations.[2]

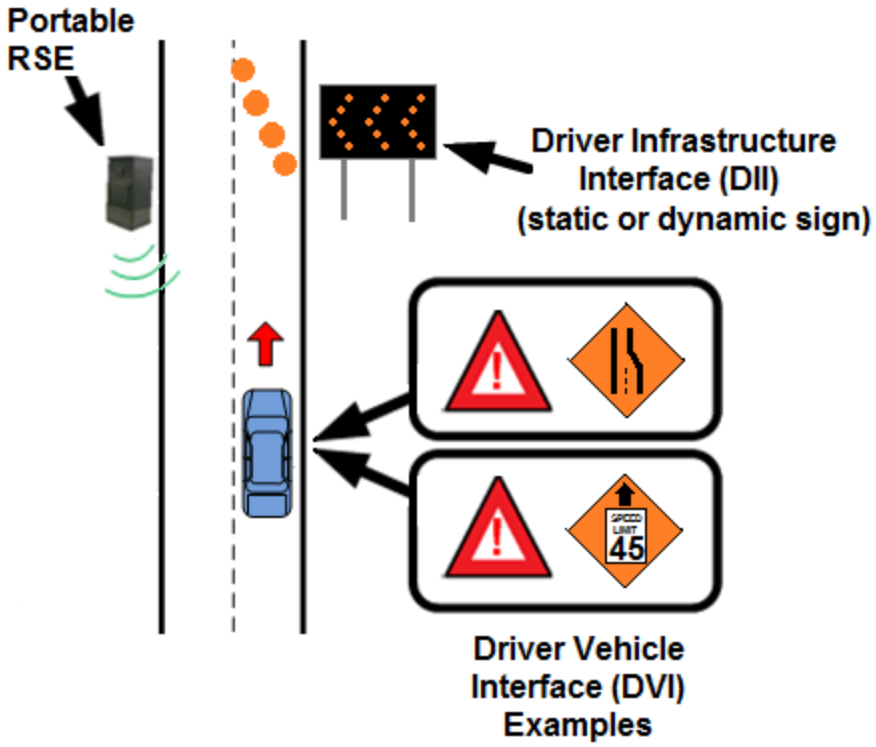
[2] Lane change alerts and warnings require *lane-level* accuracy position and map.

Figure 1-3 summarizes the proposed RSZW/LC application design for reduced speed deployment only and Figure 1-4 shows the proposed RSZW/LC application design for a reduced speed deployment that includes a changed roadway configuration.



Source: Battelle

Figure 1-3. Illustration of Reduced Speed Zone Warning Application Infrastructure and Driver Messaging

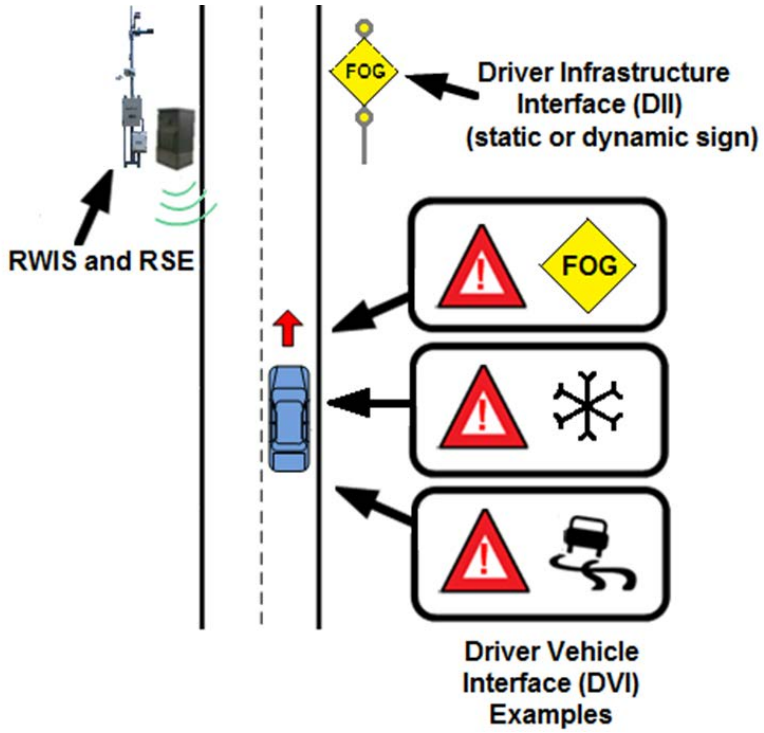


Source: Battelle

Figure 1-4. Illustration of Reduced Speed Zone Warning with Lane Change Application Infrastructure and Driver Messaging

Spot Weather Information Warning – Reduced Speed – The objective of the SWIW-RS application is to improve roadway safety by assisting drivers in avoiding weather-related crashes by informing the vehicle driver of potential weather-induced crash hazards and appropriate precautions, such as reduced speed. The application uses both infrastructure- and vehicle-based sensor data, to recommend safe speeds given current weather conditions. Recommendations are based upon available real-time weather and roadway conditions data and vehicle dynamics and stability telematics data. The application coordinates roadside messages for all vehicles with in-vehicle, vehicle-specific advisories and alerts to notify drivers in time for them to slow to the recommended safe speed before entering the weather zone.

In this application, an equipped connected vehicle approaching an equipped roadway segment will receive a message indicating adverse weather ahead, including length of adverse weather impact zone; weather data collected by road weather information systems (RWIS); and, if available, the advisory message and/or enforceable speed as recommended by the infrastructure application. The driver is issued an advisory message or alert if the vehicle application component determines that, given current operating conditions, a crash-imminent situation is possible due to the weather impacts, and that speed reduction is recommended. Figure 1-5 illustrates the proposed SWIW-RS application concept.

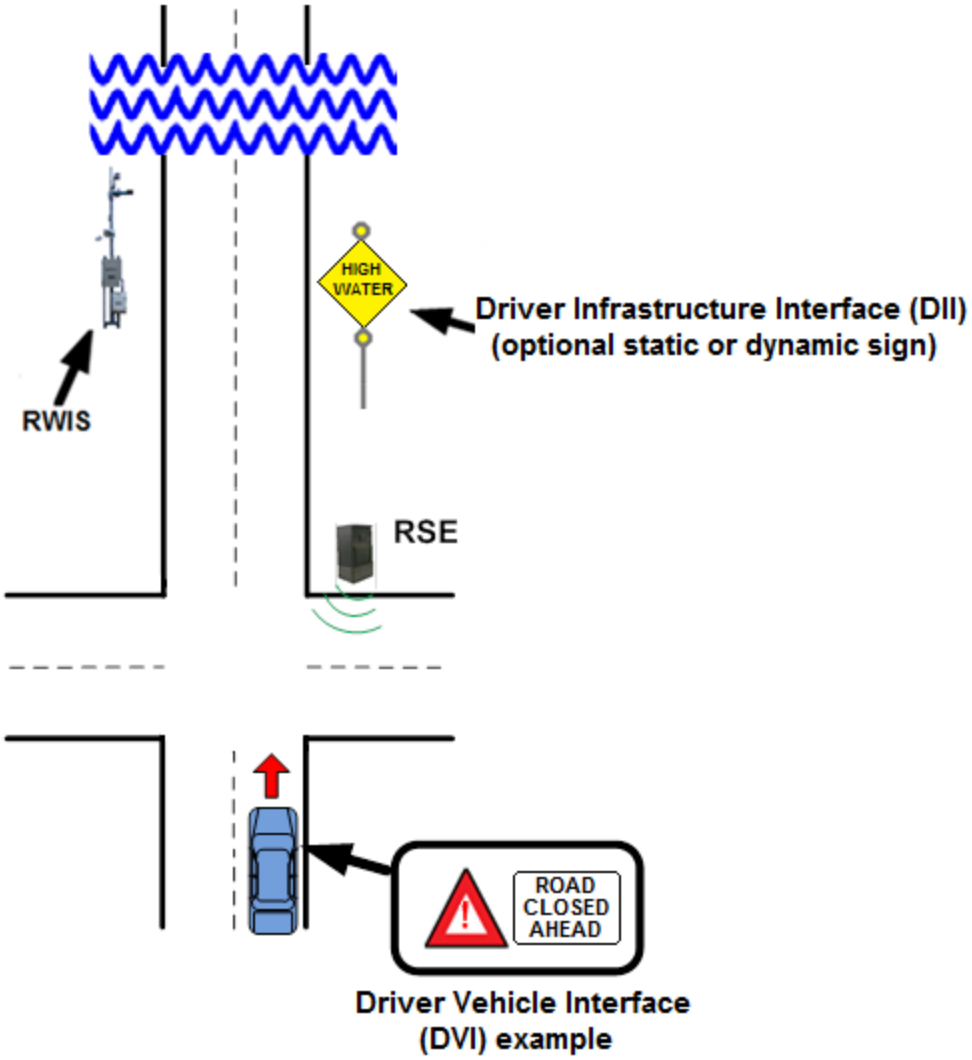


Source: Battelle

Figure 1-5. Illustration of Spot Weather Information Warning-Reduced Speed Application Infrastructure and Driver Messaging

Spot Weather Information Warning – Diversion – The objective of SWIW-D is to provide a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes due to road closures in areas prone to adverse weather impacts by advising the driver of road closure on the roadway ahead and recommendation for diversion (e.g., alternative route), when applicable. In the event of a road closure, the application will first provide an advisory message and diversion recommendation before reaching the diversion point. If the driver continues without diverting, the application continues issuing the advisory, followed by an alert and warning of the crash-imminent, road closure ahead.

In this application, an equipped vehicle approaching an equipped roadway segment will receive a message indicating adverse weather and road closures ahead, including distance to the start and end of the adverse weather impact zone; weather data collected by RWIS; and, if available, the suggested or required diversion to an alternate route. The driver is issued an advisory message about the diversion to due to a weather hazard on the roadway ahead. If the driver proceeds on the roadway beyond the diversion point, an advisory message, alert, or warning will be issued if the vehicle application component determines that, given current operating conditions, a crash-imminent situation is possible due to the weather-related road closure. Figure 1-6 illustrates the proposed SWIW-D application design.

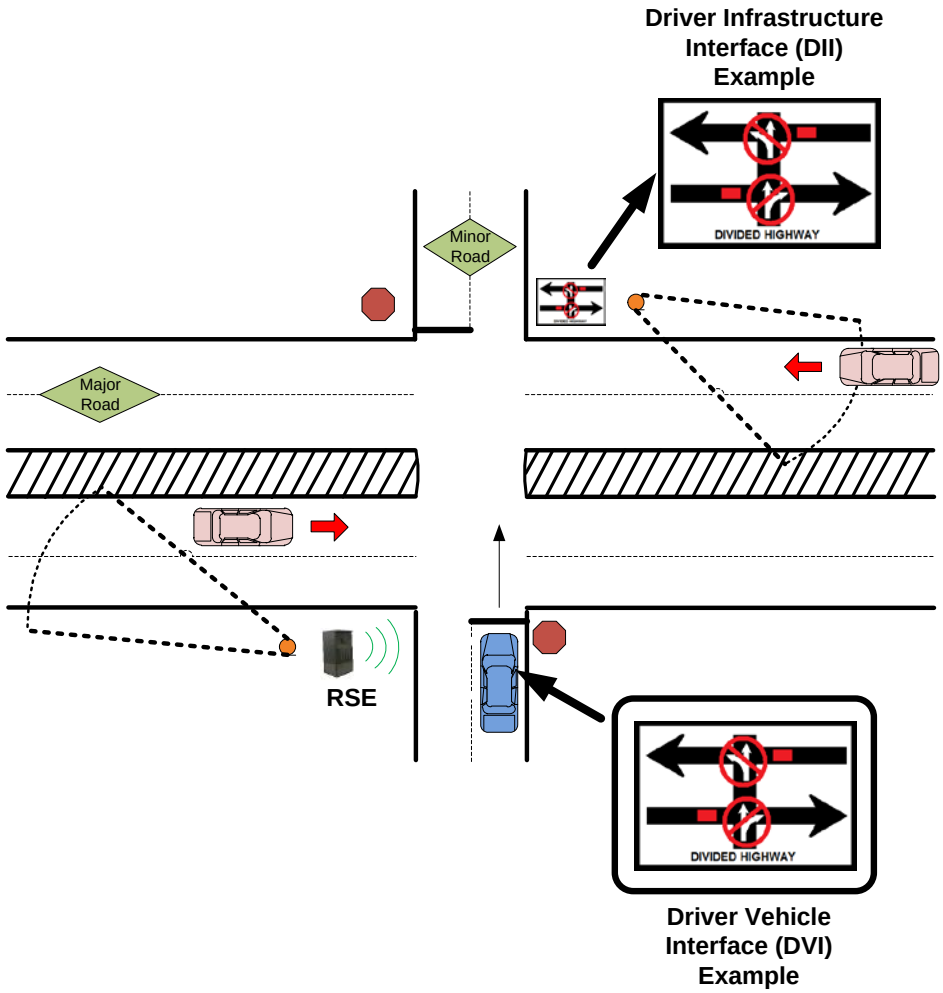


Source: Battelle

Figure 1-6. Illustration of Spot Weather Information Warning-Diversion Application Infrastructure and Driver Messaging

Stop Sign Gap Assist – The objective of the SSGA application is to improve roadway safety at non-signalized intersections where only the minor road has posted stop signs. This will be achieved through the integration of both vehicle-based and infrastructure-based technologies, including both onboard and roadside signage warning systems. The application will help drivers on a minor road stopped at an intersection understand the state of activities associated with that intersection by providing alerts and warnings of unsafe gaps on the major road. In this way, the SSGA safety application will help drivers maneuver through cross traffic, reducing the number of conflicts and crashes. The application coordinates roadside messages for all vehicles with in-vehicle, vehicle-specific advisories to notify drivers in time for them to react.

In this application, the infrastructure application component collects available infrastructure and vehicle data, most importantly from the major road vehicle detection system that detects the presence, distance, and speed of each approaching vehicle. The infrastructure application processes available data and posts an appropriate advisory message, alert, and/or warning on the DII signage when conditions are determined to be potentially unsafe for minor road drivers to proceed into the intersection. An equipped vehicle stopped at an equipped intersection receives messages from the roadside equipment and will display an appropriate advisory message, alert, and/or warning of potentially unsafe conditions for the driver on the in-vehicle DVI. Figure 1-7 illustrates the proposed SSGA application design.



Source: Battelle

Figure 1-7. Illustration of Stop Sign Gap Assist Application Infrastructure and Driver Messaging

Chapter 2 Referenced Documents

The following sections include documents that are either cited herein or were reviewed for the development of this document. Documents from U.S. DOT are presented first, followed by documents from other government and non-government organizations.

U.S. Department of Transportation

- Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications Concept of Operations Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-058. (2012).
- Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-059. (2012).
- Driver Vehicle Interface (DVI) Design Assistance for Advanced Technology Applications, Campbell, J. L., Brown, J. L., et al, National Highway Traffic Safety Administration, (in press). (Battelle Final Report to Virginia Tech Transportation Institute and National Highway Traffic Safety Administration).
- Fatality Analysis Reporting Systems (FARS). National Highway Traffic Safety Administration. http://www.nhtsa.gov/FARS
- Highway Functional Classification: Concepts, Criteria and Procedures, Federal Highway Administration, FHWA-PL-13-026, 2013 Edition
- Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 edition, Federal Highway Administration. http://mutcd.fhwa.dot.gov/.
- Vehicle-to-Infrastructure (V2I) Safety Applications Concept of Operations Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-060. (2013).
- Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements Document. FHWA Office of Safety Research and Development, Turner-Fairbank Highway Research Center. FHWA-JPO-13-061. (2013).

American Association of State Highway and Transportation Officials (AASHTO)

- The Green Book. A Policy on Geometric Design of Highways and Streets, 6th edition. 2011.

International Organization for Standardization (ISO)

- ISO 9141-2. Road vehicles – Diagnostic systems – Part 2: CARB requirements for interchange of digital information (1994).
- ISO 11898, Road vehicles – Controller area network (CAN) – Part 6: High-speed medium access unit with selective wake-up functionality

- ISO 14230-4, Road vehicles – Diagnostic systems – Keyword Protocol 2000 – Part 4 Requirements for emission-related systems
- ISO 15765, Road vehicles – Diagnostic communication over Controller Area Network (DoCAN) – Part 4: Requirements for emissions-related systems

Institute of Transportation Engineers (ITE) Standards

- ITE ATC Transportation Controller (ATC) v5.2b
- ITE Traffic Management Data Dictionary (TMDD) Standard v3.03 for the Center-to-Center Communications.

National Marine Electronics Association

- NMEA 0183 Interface Standard.

National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) Standards

- NTCIP 1103 Transportation Management Protocols.
- NTCIP 1204 v03 Object Definitions for Environmental Sensor Stations (ESS) Standard.
- NTCIP 1203 v02 Object Definitions for Dynamic Message Signs (DMS) Standard.
- NTCIP 1209 v02 Object Definitions for Transportation Sensor Systems (TSS).

Radio Technical Commission for Maritime Services

- RTCM 10403.2, Differential GNSS (Global Navigation Satellite Systems) Services – Version 3

Society of Automotive Engineers (SAE) Standards

- SAE J1211. Handbook for Robustness Validation of Automotive Electrical/Electronic Modules.
- SAE J1850 VPW, J1850 PWM. Class B Data Communications Network Interface (June 2006).
- SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary
- SAE J2178 Class B Data Communication Network Messages-Detailed Header Formats and Physical Address Assignments

Transportation Research Board (TRB)

- National Cooperative Highway Research Program (NCHRP) Report 600. Human Factors Guidelines for Road Systems, 2nd edition. (2012).

Chapter 3 Performance Requirements

3.1 Introduction and Overview

This volume of the report enumerates the performance requirements common for all six V2I Safety Applications. The safety applications described here integrate roadside and in-vehicle advisories, alerts and warnings to make the driver aware of hazards in time to take action to prevent a potential crash. The performance requirements provide requirements for both infrastructure and vehicle application components to ensure the advisories are consistent and coordinated.

In addition to common application requirements, this volume describes requirements recommended for the Infrastructure Application Platform. The Infrastructure Application Platform is the computational platform which hosts the Infrastructure Application Component and enables communication between infrastructure systems and vehicles. It provides the necessary hardware and software interfaces enabling communication with Infrastructure Wireless Data Systems, Infrastructure Data Systems, Roadside Signage System, Traffic Signal Controller, and Local/Back Office User Systems. The Infrastructure Application Platform support exchanges of the following data between infrastructure and vehicles using DSRC and other communications modes.

- Traffic Signal Phase and Timing
- Maps and roadside signage
- Infrastructure-based vehicle speed sensors
- Environmental sensor stations
- Differential GPS Position Corrections

Recommended performance requirements are provided for the Infrastructure Application Platform to inform developers and deployers of V2I Safety Applications of the functional and performance needs for an infrastructure-based computational platform necessary to support V2I application deployment.

3.1.1 Organization of this Chapter

The chapter of the volume begins by describing the V2I System of Systems, including its functional architecture, components and interfaces. This introductory material is followed by Common Application Performance Requirements, first for the Infrastructure Application Component, and then by the Vehicle Application Component. This chapter concludes with Performance Requirements for the Infrastructure Application Platform. This chapter is organized under the following headings.

- 3.1 Introduction and Overview
  - 3.1.1 Organization of this Chapter
  - 3.1.2 Structure and Format of the Performance Requirements
    - 3.1.2.1 Performance Requirements Identifier Structure
    - 3.1.2.2 Verification Methods

- 3.2 V2I System Functional Architecture
  - 3.2.1 System Components and Interfaces
    - 3.2.1.1 Driver
    - 3.2.1.2 Infrastructure Systems Components
    - 3.2.1.3 Vehicle System Components
    - 3.2.1.4 V2I/I2V Wireless Data Interface
    - 3.2.1.5 Infrastructure System Interfaces
    - 3.2.1.6 Vehicle System Interfaces
- 3.3 Common Application Performance Requirements
  - 3.3.1 Common Infrastructure Application Component Performance Requirements
  - 3.3.2 Common Vehicle Application Component Performance Requirements
  - 3.3.3 Infrastructure Application Platform Performance Requirements

In developing the performance requirements contained herein, the authors developed a framework for coordinating the delivery of roadside and in-vehicle messages to drivers. As illustrated in the V2I System of Systems description below, V2I applications are implemented in a framework of multiple existing and legacy systems that capture data, process it and issue messages to drivers and other systems.

The authors of these requirements expect that questions will arise during the design and implementation of these applications. The rationales, frameworks, and requirements presented here are expected to evolve. Understanding that different components will be developed by different agencies, the purpose here is to provide an underlying structure for discussion between these agencies to support coordination and refinement of the requirements that are necessary to successfully develop and implement the applications to achieve their safety objectives.

3.1.2 Structure and Format of the Performance Requirements

Each requirement in the following tables includes the following elements:

- **Unique Identifier** of the form **[A.B.CC.DD]**, described in more detail below.
- **Requirement Title** describes the topic of the requirement. **Requirement Titles** are presented in bold face type for readability.
- **Requirement Statement** provides the specific requirement which is subject to verification and validation, and represents the description of design, development, behavior, operation, performance, etc. of the application. **Requirement Statements** are presented in bold type face to distinguish them from supporting text including the *Requirements Elaboration.*
- *Requirements Elaboration* provides supporting text for the **Requirement Statement** that aids in understanding, interpretation and application of the **Requirement Statement** where needed. *Requirements Elaboration* text is presented in italics type face to distinguish it from the **Requirements Statement**. *Requirements Elaboration* is not necessarily subject to verification and validation, but may be useful in establishing methods and acceptance criteria for verification and validation.

- Verification Method describes how the performance requirements will be verified, whether by Inspection (I), Demonstration (D), Test (T) or Analysis (A). Each of these is described in more detail below.

3.1.2.1 Performance Requirements Identifier Structure

Performance requirements for this V2I application is organized and numbered by the application, the component, and requirement category. For consistency and accessibility the requirements are uniquely identified by a four element number of the format [A.B.CC.DD] where A designates the application, B designates the application component, CC designates the application category, and DD is the unique requirement number within the category. The [A] designators for each application are

- [1.B.CC.DD] Common Application Requirements
- [2.B.CC.DD] CSW Application Requirements
- [3.B.CC.DD] RLVW Application Requirements
- [4.B.CC.DD] RSZW/LC Application Requirements
- [5.B.CC.DD] SWIW-RS Application Requirements
- [6.B.CC.DD] SWIW-D Application Requirements
- [7.B.CC.DD] SSGA Application Requirements

The [B] designators for the application components are

- [A.1.CC.DD] Infrastructure Application Component Performance Requirements
- [A.2.CC.DD] Vehicle Application Component Performance Requirements
- [A.3.CC.DD] Infrastructure Application Platform Performance Requirements[3]

The [CC] designator for the application categories are

- [A.B.01.DD] Interfaces and Interface Specifications
- [A.B.02.DD] Functional Requirements
- [A.B.03.DD] Data Input Requirements
- [A.B.04.DD] Data Output Requirements

Common Application requirements include the following additional categories:

- [A.B.05.DD] Computation and Communication Performance Requirements
- [A.B.06.DD] Operational Performance Requirements
- [A.B.07.DD] Supportability Requirements
- [A.B.08.DD] Security Requirements
- [A.B.09.DD] Human Factors, Health and Safety Requirements
- [A.B.10.DD] Installation and Setup Requirements
- [A.B.12.DD] Operation, Maintenance and Diagnostic Requirements

[3] While outside the system of interest, candidate performance requirements are provided in Volume 1 for the Infrastructure Application Platform for reference.

- [A.B.12.DD] Documentation Requirements
- [A.B.13.DD] Staffing and Training Requirements
- [A.B.14.DD] Physical and Environmental Performance Requirements

3.1.2.2 Verification Methods

The verification method describes how the performance requirements will be verified in order to ascertain that the system of interest conforms to the requirements in this specification. The four potential methods of verification include the following.

Analysis is a verification method that utilizes established technical or mathematical models or simulations, algorithms, charts, graphs, circuit diagrams, or other scientific principles and procedures to provide evidence that stated requirements are met.

Demonstration is a verification method that generally denotes the actual operation, adjustment, or re-configuration of items to provide evidence that the designed functions were accomplished under specific scenarios.

Inspection is a verification method that consists of investigation, without the use of special laboratory appliances or procedures, of items to determine conformance to those specified requirements. Examination is generally nondestructive and typically includes the use of sight, hearing, smell, touch; and/or simple physical manipulation of the system when it is safe to do so. Inspection can also be applied to the project work products. For instance, verifying that software is developed using a certain programming language would be verified by inspection.

Testing is a verification method that generally denotes the determination of properties by instrumentation and measurement. This method includes functional operation, and involves the application of established scientific principles and procedures.

3.2 V2I System Functional Architecture

Figure 3-1 illustrates the V2I System of Systems Functional Architecture upon which the Performance Requirements are based. The figure illustrates a number of key elements concerning the architecture of the V2I safety application described in this volume. First, the V2I safety application has two core components, an Infrastructure Application Component residing and operating on an Infrastructure Application (Computing) Platform and a Vehicle Application Component residing on a Vehicle Application (Computing) Platform. Both components are necessary to achieve the safety application objectives of integrating and processing infrastructure and vehicle data and delivering coordinated messages to the driver. These two application components share data and information by exchanging messages through wireless data interface(s).

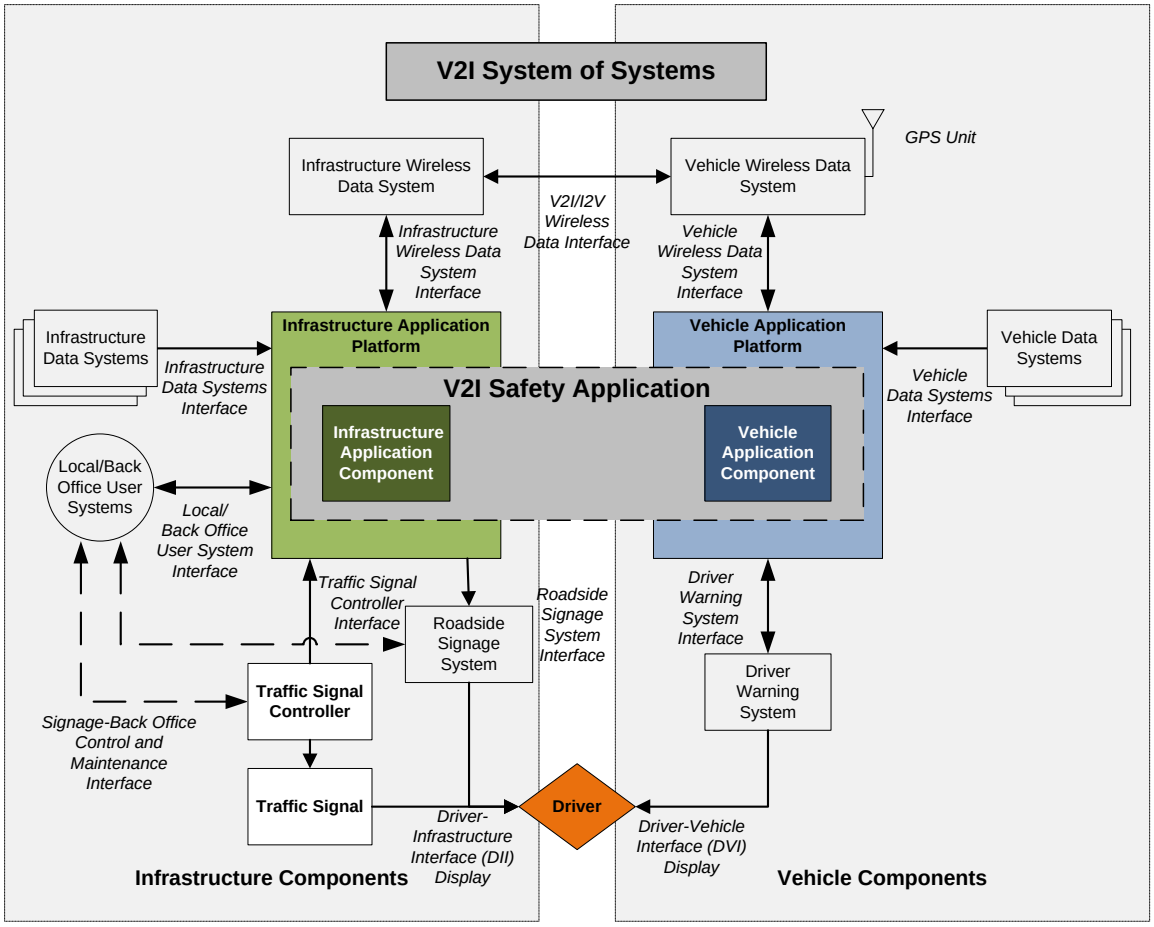
Each of the application components resides and operates on a computing platform that provides the necessary hardware and software data interfaces needed to exchange data with other systems. Each computing platform has an interface for wireless data systems that support with wireless exchange of data between the Infrastructure and Vehicle Application Components. From a requirements standpoint, the Application Components are independent from the form of wireless communication, it is expected that the primary form of communication between the two will be Dedicated Short Range Communication (DSRC).

The Infrastructure Application Platform also provides interfaces for data exchange with Infrastructure Data Systems, Local or Back Office User Systems and user interfaces, Traffic Signal Controllers and Roadside Signage Systems. The Vehicle Application Platform also provides interfaces for capture of data from vehicle systems and a driver warning system with a DVI display.

The infrastructure application component issues messages through dynamic message signs that are visible to and applicable to all approaching vehicles and drivers. The vehicle application component issues messages through a driver warning interface that may be vehicle specific or may be the same as that displayed by dynamic message and static roadside signs. This V2I Safety Application is expected to coordinate and synchronize the display of roadside and in-vehicle messages to the driver.

Vehicle-specific messages for drivers may be equally or more cautious than roadside signs, but must never be less cautious. Vehicle-specific message must never conflict with roadside messages. For example, the vehicle application component in a truck carrying an unusual load with a high center of gravity and high rollover potential may recommend a lower vehicle-specific safe speed in a curve than the infrastructure application component recommends for all vehicles. However, the vehicle application component in a sports car under good road surface conditions must not recommend a higher safe speed in a curve than does the infrastructure signage.

An important concern and rationale for developing these performance requirements is that the vehicle and infrastructure components of the applications are likely to be developed and implemented by different entities. Infrastructure components may be developed by public state and local agency infrastructure owners and contractors and vehicle components may be developed by private vehicle manufacturers and suppliers.



Source: Battelle

Figure 3-1. Functional Architecture for Connected Vehicle V2I Safety Applications

3.2.1 System Components and Interfaces

As illustrated in Figure 3-1, there many components which make up the System-of-Interest (SOI) and supporting components. These components include:

- System-Of-Interest Components
  - Infrastructure Application Component
  - Vehicle Application Component
- Supporting Components
  - Infrastructure Application Platform
  - Infrastructure Wireless Data Systems (with GPS)
  - Infrastructure Data Systems
  - Roadside Signage System
  - Traffic Signal Controller
  - Traffic Signal
  - Local/Back Office User Systems

- Vehicle Application Platform
- Vehicle Wireless Data Systems (with GPS)
- Vehicle Data Systems
- Driver Warning System
- Driver

- Interfaces
  - V2I/I2V Wireless Data Interface
  - Infrastructure Wireless Data Systems Interface
  - Vehicle Wireless Data Systems Interface
  - Infrastructure Data Systems Interface
  - Vehicle Data Systems Interface
  - Roadside Signage System Interface
  - Driver Warning System Interface
  - Local/Back Office User Systems Interface
  - Traffic Signal Controller Interface

The function of each of these components and interfaces is described below.

3.2.1.1 Driver

The Driver is the consumer of information delivered by the safety application. Static roadside signage and dynamic Roadside Signage Systems and in-vehicle Driver Warning Systems convey information to drivers such as advisories, alerts, and warnings to make the driver aware of hazards in time to take action to prevent a potential crash.

3.2.1.2 Infrastructure Systems Components

Infrastructure Application Component is the infrastructure component of the V2I safety application. It obtains data from the Vehicle Application Component through the Infrastructure Wireless Data Systems, Infrastructure Data Systems, Traffic Signal Controller and Local/Back Office User Systems, processes the data and issues appropriate message to drivers through Infrastructure Wireless Data Systems and Roadside Signage Systems. The application also issues messages containing relevant data to the Vehicle Application Component through the Infrastructure Wireless Data Systems.

Infrastructure Application Platform is the computational platform which hosts the Infrastructure Application Component and provides the necessary hardware and software interfaces enabling communication with Infrastructure Wireless Data Systems, Infrastructure Data Systems, Roadside Signage System, Traffic Signal Controller, and Local/Back Office User Systems.

Roadside Signage System receives messages from the Infrastructure Application Component and delivers dynamic advisories and alerts to all approaching vehicles from the roadside.

Infrastructure Wireless Data System receives messages from the Infrastructure Application Component through the Infrastructure Application Platform, formats and processes the messages and issues the message via wireless communications to vehicles within wireless communication range. The System also performs the inverse, receiving wireless messages from nearby vehicles, formatting and processing the message and issuing the message to the Infrastructure Application Component through the Infrastructure Application Platform. The system also obtains UTC time.

Local/Back Office User System provides a technical user interface for the installation, configuration, maintenance, diagnostics, and management of the Infrastructure Application Component. The system may be a computer that is attached locally and temporarily to perform these functions or the system may connect remotely via dedicated lines or the Internet to perform these functions. The system may provide a function for upload or download of configuration and data files to the Infrastructure Application Platform. The system may also provide a connection to obtain GPS differential correction data.

Infrastructure Data Systems provide infrastructure data and information to the Infrastructure Application Component through the Infrastructure Application Platform. Examples of relevant data include weather information, road surface condition data, visibility data, and infrastructure-based vehicle detection and speed data.

Traffic Signal Controller is the external component that provide traffic signal phase and timing data required by some V2I Safety Applications through the Infrastructure Application Platform.

Traffic Signal is the traditional "driver display" component of the Traffic Signal Controller.

3.2.1.3 Vehicle System Components

Vehicle Application Component is the vehicle component of the V2I safety application. It obtains data from the Infrastructure Application Component through Vehicle Wireless Data Systems, Vehicle Data Systems, processes the data and issues appropriate messages to drivers through the Driver Warning System and Driver Vehicle Interface.

Vehicle Application Platform is the computational platform which hosts the Vehicle Application Component and provides the necessary hardware and software interfaces enabling communication with Vehicle Wireless Data Systems, Vehicle Data Systems, and the Driver Warning System.

Driver Warning System is the component which collects and arbitrates messages, advisories, alerts and warnings and delivers them to the driver. These alerts may be visual, aural, haptic, or some other means that captures the driver's attention and conveys the relevant information. When multiple safety applications are hosted on the Vehicle Applications Platform, the Driver Warning System will prioritize and arbitrate alerts and warnings from the multiple safety applications. Note: The placement of the Driver Warning System shown in Figure 3-1 is intended to show representative functionality and is not meant to restrict implementation.

Vehicle Wireless Data System receives messages from the Vehicle Application Component through the Vehicle Application Platform, formats and processes the messages and issues the message via wireless communications to Infrastructure Wireless Data Systems within wireless communication range. This system also performs the inverse, receiving wireless messages from nearby infrastructure, formatting and processing the message and issuing the message to the Vehicle Application Component through the Vehicle Application Platform. This system also obtains GPS location and time. It may include a processor for GPS differential correction.

Vehicle Data Systems represent systems contained within the vehicle that provide vehicle-related information to the Vehicle Application Component. Information provided may come from a positioning system, vehicle data bus, sensors, actuators on the vehicle, or stability systems. Specific interfaces to the original equipment manufacturers' (OEM) vehicle systems are dependent on specific information required to support the safety application.

3.2.1.4 V2I/I2V Wireless Data Interface

V2I/I2V Wireless Data Interface is the wireless communications interface that communicates relevant data between the Infrastructure and Vehicle Application Components through their respective Wireless Data Systems and Application Platforms.

3.2.1.5 Infrastructure System Interfaces

Infrastructure Wireless Data System Interface is the interface between the Infrastructure Application Platform and the Infrastructure Wireless Data Systems Component. This interface is used by the Infrastructure Applications Platform and the Infrastructure Applications Components to send and receive data to nearby vehicles via the V2I/I2V Wireless Data Interface.

Infrastructure Data Systems Interface is the interface between the Infrastructure Application Platform and Infrastructure Data Systems. The interface is used by Infrastructure Applications Platform to and Infrastructure Applications Components to capture data from infrastructure sensor systems such as weather information, road surface condition data, visibility data, and infrastructure-based vehicle detection and speed data.

Roadside Signage System Interface is the interface between the Infrastructure Applications Platform and the Roadside Signage System. The interface is used by Infrastructure Applications Platform to and Infrastructure Applications Components to send advisory and alert messages to local dynamic message signs at the roadside for display to all approaching vehicles.

Local/Back Office User System Interface supports IP communication with a computer that is attached locally or remotely via dedicated lines or the Internet to perform upload and download of data files as well as installation, configuration, maintenance, diagnostics, and management of the Infrastructure Application Component.

Traffic Signal Controller Interface is the interface between the Infrastructure Applications Platform and the local Traffic Signal Controller. The interface is used by Infrastructure Applications Platform to and Infrastructure Applications Components to capture traffic signal phase and timing data required by some V2I Safety Applications.

3.2.1.6 Vehicle System Interfaces

Vehicle Wireless Data System Interface is the interface between the Vehicle Application Platform and the Vehicle Wireless Data Systems component. This interface is used by the Vehicle Applications Platform and the Vehicle Applications Components to send and receive data to nearby infrastructure via the V2I/I2V Wireless Data Interface.

Vehicle Data Systems Interface is the interface between the Vehicle Application Platform and Vehicle Data Systems. The interface is used by Vehicle Applications Platform and Vehicle Applications Components to capture data from vehicle systems such as a positioning system, vehicle data bus, sensors, actuators on the vehicle, or stability systems.

Driver Warning System Interface is the interface between the Vehicle Application Platform and Driver Warning System. The interface is used by Vehicle Applications Platform and Vehicle Applications Components to send messages, advisories, alerts and warnings to the Warning System for arbitration and delivery to the driver.

3.3 Common V2I Safety Application Performance Requirements

This section of the report catalogs the Infrastructure Application Component Performance Requirements in Section 3.3.1, the Vehicle Application Component Performance Requirements in Section 3.3.2 and the Infrastructure Application Platform Performance Requirements in Section 3.3.3.

3.3.1 Common Infrastructure Application Component Performance Requirements

Table 3-1 catalogs the common performance requirements for the Infrastructure Application Components for all six applications under consideration. These were developed based upon the V2I Functional Architecture in Figure 3-1 and the integration strategy described for each of the applications. It is expected that, as connected vehicle technology evolves and vehicle and infrastructure application component owners develop this and other V2I Safety Applications, the rationales, frameworks, and performance requirements presented here will evolve. Accordingly, before embarking upon design and development, application owners should update and refine the requirements to reflect current standards and policies. It is the responsibility of the designer to ensure that the resulting applications do not conflict with applicable published state and national regulations, policies, and guidelines.

Table 3-1. Common Infrastructure Application Component Performance Requirements

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.01	**Common Infrastructure Application Component Requirements**			
1.01.01	**Common Infrastructure Application Component Interfaces and Interface Specifications**			
[1.01.01.01]	**I2V Wireless Position Correction Message Input Interface**	**The Infrastructure Application Component GPS Position Correction Message Handler shall obtain Position Correction Data from the Local/Back Office User Systems Interface.**	*Position correction data is typically obtained from reference stations via the Internet.*	D
[1.01.01.02]	**I2V Wireless Position Correction Message Output Interface**	**The Infrastructure Application Component GPS Position Correction Message Handler shall issue I2V Wireless Position Correction Messages through the Infrastructure Wireless Data Systems Interface to the Infrastructure Wireless Data Systems.**		D
[1.01.01.03]	**I2V Wireless Map Message Input Interface**	**The Infrastructure Application Component Map Message Handler shall obtain Map Data from Map data files stored on the Infrastructure Application Platform.**		D
[1.01.01.04]	**I2V Wireless Map Message Output Interface**	**The Infrastructure Application Component Map Message Handler shall issue I2V Wireless Map Messages through the Infrastructure Wireless Data Systems Interface to the Infrastructure Wireless Data Systems.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.01.02	**Common Infrastructure Application Component Functional Requirements**			
[1.01.02.01]	**Operating Platform**	**The Infrastructure Application Component shall operate on the Infrastructure Application Platform specified under Infrastructure Application Platform Requirements.**		D
[1.01.02.02]	**Vehicle Application Component Data Exchange**	**The Infrastructure Application Component shall exchange data with the Vehicle Application Component through the Infrastructure Wireless Data Systems Interface.**		D
[1.01.02.03]	**Vehicle Application Component Data Exchange Specifications**	**Data exchanged between the Infrastructure Application Component and the Vehicle Application Component shall conform to SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D
[1.01.02.04]	**Interfaces – Maintenance**	**The Infrastructure Application Component shall have a Maintenance Interface to support installation, configuration, upgrades and detailed diagnostics of the Component.**		D
[1.01.02.05]	**Interfaces – Technical Support Local and Remote Access**	**The Infrastructure Application Component Maintenance Interface shall be accessible by both local and remote users through the Local/Back Office System Interface.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.02.06]	**Interfaces – Application User Interface**	**Where required by the application, the Infrastructure Application Component shall have an Application User Interface to display operational status of the application and to support required user interactions.**		D
[1.01.02.07]	**Interfaces – Application User Interface Local and Remote Access**	**The Infrastructure Application Component Application User Interface shall be accessible by both local and remote users through the Local/Back Office System Interface.**		D
[1.01.02.08]	**Interfaces – Uploading and Downloading of Application Data and Log Files**	**The Infrastructure Application Component shall store configuration, data and log files in nonvolatile memory.**	*The Infrastructure Application Component should support upload of data files, locally or remotely, containing static infrastructure data such as road map and geometry generated elsewhere.*	D
[1.01.02.09]	**Interfaces – Uploading and Downloading of Application Data and Log Files**	**The Infrastructure Application Component shall support secure, local or remote uploading and downloading of application data and log files through the Local/Back Office User Interface.**		D
[1.01.02.10]	**Error Handling – General**	**The Infrastructure Application Component shall continue operation until an error occurs that puts it in Degraded mode.**	*The Infrastructure Application Component should, to the extent possible, recover gracefully from transient error conditions and return to a normal operating condition.*	D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.02.11]	**Error Handling – Interface Communication Errors**	**In the event of a configurable number of consecutive Interface Communication Errors, the Infrastructure Application Component shall begin operating in Degraded Mode.**		D
[1.01.02.12]	**Error Handling – Interface Communication Error Notifications**	**In the event of a configurable number of consecutive Interface Communication Errors, the Infrastructure Application Component shall issue error codes to relevant external components through the applicable interface indicating that Interface Communication Errors have occurred and that the Infrastructure Application Component is operating in Degraded Mode.**		D
[1.01.02.13]	**Error Handling – Computational Errors**	**In the event of a configurable number of consecutive Computational Errors, the Infrastructure Application Component shall begin operating in Degraded Mode.**	*The Infrastructure Application Component should, to the extent possible, recover gracefully from transient error conditions and return to a normal operating condition. For example arithmetic and register overflows.*	D
[1.01.02.14]	**Error Handling – Computational Error Notifications**	**In the event of a configurable number of consecutive Computational Errors, the Infrastructure Application Component shall issue error codes to relevant external components through the applicable interface indicating that Computational Errors have occurred and that the Infrastructure Application Component is operating in Degraded Mode.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.02.15]	**Logging – Errors**	**The Infrastructure Application component shall log Application Level error conditions along with relevant diagnostic context of the error.**	*Detail and content of log messages is typically controlled via a configuration parameter, specifying more or less detail depending on the component's desired mode of operation.*	D
[1.01.02.16]	**GPS Position Correction Message Handler**	**When Lane Level Positioning is required, the Infrastructure Application Component shall have a GPS Position Correction Message Handler.**		D
[1.01.02.17]	**I2V Wireless Position Correction Message Initiation**	**The GPS Position Correction Message Handler shall obtain Position Correction Data input upon initiation of the component.**		D
[1.01.02.18]	**I2V Wireless Position Correction Message Input Refresh Rate**	**The GPS Position Correction Message Handler shall refresh Position Correction Data input at a configurable frequency.**		D
[1.01.02.19]	**I2V Wireless Position Correction Message Issuance**	**The GPS Position Correction Message Handler shall compile and issue an I2V Wireless Position Correction Message at a configurable frequency.**		D
[1.01.02.20]	**Map Message Handler**	**The Infrastructure Application Component shall have a Map Message Handler.**		D
[1.01.02.21]	**Map Message Handler Data Upload**	**The Infrastructure Application Component shall support upload and local storage of Map Message Data on the Infrastructure Application Platform.**		D
[1.01.02.22]	**I2V Wireless Map Message Initiation**	**The Map Message Handler shall obtain Map Data input upon initiation of the Handler.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.02.23]	**I2V Wireless Map Message Input Data Refresh Rate**	**The Map Message Handler shall refresh Map Data input at a configurable frequency.**		D
[1.01.02.24]	**I2V Wireless Map Message Issuance**	**The Map Message Handler shall compile and issue an I2V Wireless Map Message at a configurable frequency.**		D
1.01.03	**Common Infrastructure Application Component Data Input Requirements**			
[1.01.03.01]	**Data – Input Validation**	**The Infrastructure Application Component shall perform range and validity checks on all data inputs and shall log applicable Input Validation error messages.**		D
[1.01.03.02]	**Data – Input Validation Functional Failure**	**In the event of an Input Validation Error, the Infrastructure Application Component shall not issue functional output messages to Wireless Data Systems Interface or other external components.**		D
[1.01.03.03]	**Data – Erroneous Data Disposition**	**In the event of an Input Validation Error, the Infrastructure Application Component shall discard the erroneous data.**		D
[1.01.03.04]	**Data – Input Validation Error Recovery**	**In the event of an Input Validation Error, the Infrastructure Application Component shall continue to process input data at the prescribed rate and continue operation.**	*The Infrastructure Application Component should, to the extent possible, recover gracefully from transient error conditions and return to a normal operating condition.*	D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.03.05]	**Data – Input Validation Error Degraded Operation**	**In the event of a configurable number of consecutive Input Validation Errors, the Infrastructure Application Component shall begin operating in Degraded Mode.**		D
[1.01.03.06]	**Data – Input Validation Error Degraded Operation Notification**	**In the event of a configurable number of consecutive Input Validation Errors, the Infrastructure Application Component shall issue error codes to relevant external components through the applicable interface indicating that Input Validation Error has occurred and that the Infrastructure Application Component is operating in Degraded Mode.**		D
[1.01.03.07]	**Data – Input Validation Error Degraded Operation Recovery**	**In the event of a configurable number of consecutive Input Validation Errors, the Infrastructure Application Component shall refresh input data and perform validity checks once per hour. In the event a configurable number of consecutive input data sets are received without Input Validation Errors, the Infrastructure Application Component shall resume normal function.**	*In the event of multiple consecutive input data errors, the Application Component should enter Degraded Operational Mode in which it periodically checks for corrected input data and resumes operation upon resumption of useable input data.*	D
[1.01.03.08]	**I2V Wireless Position Correction Message Input Content**	**The I2V Wireless Position Correction Message GPS Differential Correction input data shall contain data specified in MSG_RTCM_Corrections from SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.03.09]	I2V Wireless Map Message Input Content	The I2V Wireless Map Message Input shall contain data specified in MSG_MapData (MAP) from SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.		D
1.01.04	Common Infrastructure Application Component Data Output Requirements			
[1.01.04.01]	Data – Output Validation	The Infrastructure Application Component shall perform range and validity checks on all data outputs and shall log applicable Output Validation error messages.		D
[1.01.04.02]	Data – Erroneous Data Disposition	In the event of an Output Validation Error, the Infrastructure Application Component shall discard the erroneous output.		D
[1.01.04.03]	Data – Output Validation Functional Failure	In the event of an Output Validation Error, the Infrastructure Application Component shall not issue functional output messages to Wireless Data Systems Interface or other external components.		D
[1.01.04.04]	Data – Output Validation Error Recovery	In the event of an Output Validation Error, the Infrastructure Application Component shall continue to process data at the prescribed rate and continue operation.		D
[1.01.04.05]	Data – Output Validation Error Degraded Operation	In the event of a configurable number of consecutive Output Validation Errors, the Infrastructure Application Component shall begin operating in Degraded Mode.		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.04.06]	**Data – Output Validation Error Degraded Operation Notification**	**In the event of a configurable number of consecutive Output Validation Errors, the Infrastructure Application Component shall issue error codes to relevant external components through the applicable interface indicating that Output Validation Error has occurred and that the Infrastructure Application Component is operating in Degraded Mode.**		D
[1.01.04.07]	**I2V Wireless Position Correction Message Output Specifications**	**The I2V Wireless Position Correction Message Output shall conform to the MSG_RTCM_Corrections from SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D
[1.01.04.08]	**I2V Wireless Map Message Output Specifications**	**The I2V Wireless Map Message Output shall conform to the MSG_MapData (MAP) from SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D
1.01.05	**Common Infrastructure Application Component Computation and Communication Performance Requirements**			
[1.01.05.01]	**Operational Hardware Resources**	**The Infrastructure Application Component shall function using interfaces available on the Infrastructure Application Platform.**		D
[1.01.05.02]	**Application Processing Speed**	**The Infrastructure Application Component shall perform the functions described under Infrastructure Application Functional Requirements at a frequency of at least 10 Hz.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.05.03]	**Infrastructure Data Systems Vehicle Speed Accuracy**	**Infrastructure Systems Message vehicle speed data shall be accurate to within 1 meter per second.**		D
1.01.06	**Common Infrastructure Application Component Operational Performance Requirements**			
[1.01.06.01]	**Lane Level Position Accuracy**	**For the purposes of these requirements, Lane Level Position Accuracy is defined as a R95 Probability of horizontal position accuracy of less than or equal to 2 meters.**	*R95 is defined as the radius of a circle centered on the true antenna position that contains 95% of the actual GPS measurements.*	A
[1.01.06.02]	**Road Level Position Accuracy**	**For the purposes of these requirements, Road Level Position Accuracy is defined as a R95 Probability of horizontal position accuracy of less than or equal to 7.5 meters.**	*R95 is defined as the radius of a circle centered on the true antenna position that contains 95% of the actual GPS measurements.*	A
[1.01.06.03]	**Roadway Classes**	**The Infrastructure Application Component shall meet its functional requirements on the functional classes of roadway and levels of service (LOS) on which it will be deployed. FHWA's "Highway Functional Classification: Concepts, Criteria and Procedures", FHWA-PL-13-026 and AASHTO's "A Policy on Geometric Design of Highways and Streets", AASHTO, 2001, are referenced for guidance.**		D
[1.01.06.04]	**Roadway Geometry**	**The Infrastructure Application Component shall meet its functional requirements on the road geometries on which it will be deployed. AASHTO's "A Policy on Geometric Design of Highways and Streets", AASHTO, 2001, is referenced for guidance.**	*The defined functional classes of roadways can be found in FHWA's "Functional Classification Guidelines". The defined LOS can be found in AASHTO's "A Policy on Geometric Design of Highways and Streets".*	D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.06.05]	**Connected Vehicle Equipped and Unequipped Vehicles**	**The Infrastructure Application Component shall support advisories, alerts, and warnings for vehicles, equipped and unequipped with connected vehicle technology.**		D
[1.01.06.06]	**Directional Applicability**	**The Infrastructure Application Component shall issue advisories, alerts and wireless messages applicable to the vehicles' direction of travel.**		D
[1.01.06.07]	**Mixed Vehicle Traffic**	**The Infrastructure Application Component shall issue advisories, alerts, and warnings applicable to all vehicles licensed to operate on the roadway.**	*Including passenger cars and commercial motor vehicles and transit buses.*	D
[1.01.06.08]	**Multiple Lane Roadways**	**The Infrastructure Application Component shall support roadways of up to 5 adjacent lanes traveling in each direction.**		A
[1.01.06.09]	**Traffic Volume**	**The Infrastructure Application Component shall support advisories, alerts, and warnings for roadways operating at up to 150 percent of design capacity.**		A
[1.01.06.10]	**Vehicle Approaching from Multiple Lanes**	**The Infrastructure Application Component shall support advisories, alerts, and warnings for vehicles approaching in up to 5 adjacent lanes.**		A
[1.01.06.11]	**Vehicle Spacing**	**The Infrastructure Application Component shall support advisories, alerts, and warnings for vehicles spaced longitudinally as close as 2 meters.**		A

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.06.12]	**Vehicle Speeds**	**The Infrastructure Application Component shall support advisories, alerts, and warnings for vehicles traveling at speeds from 1 to 160 kph.**		A
1.01.07	**Common Infrastructure Application Component Supportability Requirements**			
[1.01.07.01]	**Modularity (Software)**	**The software architecture of the Infrastructure Application Component shall be organized to co-exist with multiple, independent Infrastructure Application Components on the Infrastructure Application Platform without conflict or interference.**		D
[1.01.07.02]	**Portability (Software)**	**The Infrastructure Application Component shall be designed such that platform-dependent code is identified and encapsulated wherever and whenever performance considerations permit.**	*Aside from industry best-practice design principles, this requirement is meant to reduce the cost of the potential porting of the system software to other host machines and/or operating systems.*	A
[1.01.07.03]	**Vehicle Communication Scalability (Software)**	**The Infrastructure Application Component shall support communication with a number of Vehicle Application Components scalable up to the number of vehicles that can be physically in communication range of the Infrastructure Application Platform.**		A

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.01.08	**Common Infrastructure Application Component Security Requirements**			
[1.01.08.01]	**Access Control**	**Access to modify the Infrastructure Application Component and its configuration, data and log files, shall be restricted to personnel authorized by the Operating Agency.**		D
1.01.09	**Common Infrastructure Application Component Human Factors, Health and Safety Requirements**			
[1.01.09.01]	**Safety**	**The Infrastructure Application Component shall not issue inaccurate messages to drivers during installation, configuration, operation, or diagnostics.**	*The application must not create a safety hazard during installation, configuration, operation, or diagnostics.*	D
[1.01.09.02]	**Driver Capabilities**	**The V2I Safety Infrastructure Application Component shall support the physical and cognitive capabilities of drivers qualified to obtain a driver's license. National Cooperative Highway Research Program (NCHRP) Report 600A "Human Factors Guidelines for Road Systems" is referenced for Guidance.**		A
1.01.10	**Common Infrastructure Application Component Installation and Setup Requirements**			
[1.01.10.01]	**Installation and Maintenance Interface**	**The Infrastructure Application Component shall support installation and maintenance of software components through the Local/Back Office Systems Interface.**	*Enables system installation and maintenance updates both remotely and locally.*	D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.11.02]	**Installation and Maintenance Entities**	**Installation and maintenance of the Infrastructure Application Component software shall be limited to authorized entitles.**		D
1.01.11	**Common Infrastructure Application Component Operation, Maintenance and Diagnostic Requirements**			
[1.01.11.01]	**Function – Self-Diagnostics**	**The Infrastructure Application Component shall perform self-diagnostics upon power up and at configurable periodic intervals.**		D
[1.01.11.02]	**Operational Mode – Determination**	**The Infrastructure Application Component shall determine the operating level/mode of operation based on the results of software errors and/or self-diagnostic tests of the application and self-diagnostic tests of the Infrastructure Application Platform.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.11.03]	**Operation Mode – Required Modes**	**The Infrastructure Application Component shall support the following operational modes:** **Full Operation – Connected (Online)** **Full Operation – Reachback (Online)** **Full Operation – Standalone (Online)** **Degraded Operation – (Online)** **Failed (Offline)** **Diagnostic Operation (Offline)**	*Operational Modes are determined through self diagnostics and error handling.* *Full Operation – Connected Mode – TCP/IP communications to a Local or Back Office System are continuously available* *Full Operation – Reachback Mode – TCP/IP communications to a Local or Back Office System are available temporarily* *Full Operation – Standalone Mode – Communications with a Local or Back Office System are not available* *Degraded Operation – Result of partial failure, such as failure of an input data validity check or failure of one or more of the data input or output interfaces, that supports partial operation only. Partial operation may include examples such as the ability to issue Driver Infrastructure Interface messages only, the ability to send I2V communication messages only.*	D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.11.04]	**Full Operation – Connected Mode Criterion**	**The Infrastructure Application Component shall maintain (or restore) itself in Full Operation – Connected Mode when self-diagnostic tests are passed and when TCP/IP communications to a Local or Back Office System are continuously available through the Infrastructure Application Platform.**		D
[1.01.11.05]	**Full Operation – Reachback Mode Criterion**	**The Infrastructure Application Component shall maintain (or restore) itself in Full Operation – Reachback mode when self-diagnostic tests are passed and when TCP/IP communications to a Local or Back Office System are available temporarily through the Infrastructure Application Platform Local/Back Office User Systems Interface upon request of the Infrastructure Application Component.**		D
[1.01.11.06]	**Full Operation – Standalone Mode Criterion**	**The Infrastructure Application Component shall maintain (or restore) itself in Full Operation – Standalone mode when self-diagnostic tests are passed and communications with a Local or Back Office System are not available.**		D
[1.01.11.07]	**Automatic Adjustment of Operation Mode**	**If the Infrastructure Application Component is configured to communicate with a Back Office System, the Infrastructure Application Component shall monitor the Local/Back Office User Interface and automatically adjust its mode of operation (connected, reachback or standalone) to correspond to errors or failure of the Back Office Communications.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.11.08]	**Degraded Mode Criterion**	**The Infrastructure Application Component shall operate in Degraded Mode in the event of a partial failure.**	*Examples of partial failure include failure of an input data validity check or failure of one or more of the data input or output interfaces, such as the ability to issue messages only to the Roadside Signage System or only to Wireless Data Systems. Partial operation may include examples that prevent the application from processing data and from issuing any message or output, other than default advisory, caution or error messages.*	D
[1.01.11.09]	**Failed Mode Criterion**	**The Infrastructure Application Component shall enter Failed-Offline Mode and cease issuing messages in the event of an error and/or self-diagnostic failure or any event that prevents the application from issuing accurate messages to other system components.**		D
[1.01.11.10]	**Maintenance and Diagnostic Mode Criterion**	**The Infrastructure Application Component shall have a Maintenance and Diagnostic mode to support installation, operation, and diagnostics of the Infrastructure Application Components through a maintenance interface.**		D
[1.01.11.11]	**Operational Status Reporting – Connected Mode**	**While in Full Operation – Connected Mode, the Infrastructure Application Component shall report operational status to the Local or Back Office User, at configurable periodic intervals.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.11.11]	**Degraded or Failed Status Reporting**	**Where necessary to ensure vehicle and roadway safety, the Infrastructure Application Component shall communicate degraded or failed status to the Infrastructure Wireless Data Systems, the Local/Back Office User Systems, the Traffic Signal Controller and the Roadside Signage System.**		D
[1.01.11.12]	**Logging – Error and Diagnostic Data**	**The Infrastructure Application Component shall log self-diagnostic test information which contains, at a minimum, the following information:** **1. Operational Mode and Online/Offline status** **2. Self-diagnostic test information** **a. Date and time of test** **b. Test performed** **c. Result of test (Pass/Fail)** **d. Actions resulting from Failed Test** **e. Relevant diagnostic and maintenance data to support debugging.**		D
[1.01.11.13]	**Logging – Diagnostic Data**	**The Infrastructure Application Component shall log all errors and relevant diagnostic and maintenance data to support debugging.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.01.11.14]	**Logging – Error and Diagnostic Data Logging Retention**	**The Infrastructure Application Component shall maintain historical information of self-diagnostic tests for a configurable period in non-volatile storage.**	*Non-volatile storage refers to storage that remains intact even when there is no power. (It is left up to the implementer to determine if the retention of data is a fixed window of time or if it is based on a fixed amount of storage.)*	D
[1.01.11.15]	**Logging – Diagnostic Data Storage Overflow**	**If diagnostic data exceeds available memory resources, records shall be overwritten on a first in/first out basis.**		D
[1.01.11.16]	**Operational Status Reporting – Reachback Mode**	**While in Full Operation – Reachback Mode, the Infrastructure Application Component shall report operational status to the Local or Back Office User, upon initiation of communication and at configurable periodic intervals while connected.**		D

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.01.12	**Common Infrastructure Application Component Documentation Requirements**			
[1.01.12.01]	**User Manual Documentation**	**The Infrastructure Application Component shall include online Technical User Manual which includes, at a minimum, the following information:** - **Design and Functions of the Infrastructure Application Component** - **Specifications for Interfaces** - **Specifications for Messages Input to and Output from the Infrastructure Application Component** - **Error codes and error messages and relevant troubleshooting and diagnostic Information** - **Instructions for installation, operation, and diagnostics for the Infrastructure Application Component**		I
1.01.13	**Common Infrastructure Application Component Staffing and Training Requirements**			
[1.01.13.01]	**Training Material Documentation**	**The Infrastructure Application Component shall include online training materials for installation, operation, and diagnostics procedures for the Component.**		I

Table 3-1. Common Infrastructure Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.01.14	**Common Infrastructure Application Component Physical and Environmental Performance Requirements**			
[1.01.14.01.00]	**Operational Platform**	**The Infrastructure Application Component shall be capable of being installed, operated, maintained and debugged on the Infrastructure Application Platform.**		D

3.3.2 Common Vehicle Application Component Performance Requirements

Table 3-2 catalogs the common performance requirements for the Vehicle Application Components for all six applications under consideration. These were developed based upon the V2I Functional Architecture in Figure 3-1 and the integration strategy described for each of the applications. It is expected that, as connected vehicle technology evolves and vehicle and infrastructure application component owners develop this and other V2I Safety Applications, the rationales, frameworks, and performance requirements presented here will evolve. Accordingly, before embarking upon design and development, application owners should update and refine the requirements to reflect current standards and policies. It is the responsibility of the designer to ensure that the resulting applications do not conflict with applicable published state and national regulations, policies, and guidelines.

Table 3-2. Common Vehicle Application Component Performance Requirements

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.02	**Common Vehicle Application Component Requirements**			
1.02.01	**Common Vehicle Application Component Interfaces and Interface Specifications**			
[1.02.01.01]	**GPS Position Data Interface**	**The Vehicle Application Component GPS Position Message Handler shall obtain GPS Position from the Vehicle Wireless Data Systems Interface.**		D
[1.02.01.02]	**I2V Wireless Position Correction Message Interface**	**The Vehicle Application Component GPS Position Message Handler shall obtain the I2V Wireless Position Correction Message from the Vehicle Wireless Data System Interface.**		D
[1.02.01.03]	**I2V Wireless Map Message Interface**	**The Vehicle Application Component GPS Position Message Handler shall obtain Wireless Map Message from the Vehicle Wireless Data System Interface.**		D
1.02.02	**Common Vehicle Application Component Functional Requirements**			
[1.02.02.01]	**Infrastructure Application Component Data Exchange**	**The Vehicle Application Component shall exchange data with the Infrastructure Application Component through the Vehicle Wireless Data Systems Interface.**		D
[1.02.02.02]	**Infrastructure Application Component Data Exchange Specifications**	**Data exchanged between the Vehicle Application Component and the Infrastructure Application Component shall conform to SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.02.03]	**Interfaces – Maintenance**	**The Vehicle Application Component shall have a Maintenance Interface to support installation, configuration, upgrades and detailed diagnostics of the Component.**		D
[1.02.02.04]	**Interfaces – Application User Interface**	**The Vehicle Application Component shall have an Application User Interface to display operational status of the application and, if required, to support required user interactions.**		D
[1.02.02.05]	**Interfaces – Storage of Application Data and Log Files**	**The Vehicle Application Component shall store configuration, data and log files in nonvolatile memory.**		D
[1.02.02.06]	**Error Handling – General**	**The Vehicle Application Component shall continue operation until an error occurs that puts it in Degraded mode.**		D
[1.02.02.07]	**Error Handling – Interface Communication Errors**	**In the event of a configurable number of consecutive Interface Communication Errors, the Infrastructure Application Component shall begin operating in Degraded Mode.**		D
[1.02.02.08]	**Error Handling – Interface Communication Error Notifications**	**In the event of a configurable number of consecutive Interface Communication Errors, the Infrastructure Application Component shall issue error codes to relevant external components through the applicable interface indicating that Interface Communication Errors have occurred and that the Vehicle Application Component is operating in Degraded Mode.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.02.09]	**Error Handling – Computational Errors**	**In the event of a configurable number of consecutive Computational Errors, the Vehicle Application Component shall begin operating in Degraded Mode.**	*The Vehicle Application Component should, to the extent possible, recover gracefully from transient error conditions and return to a normal operating condition.*	D
[1.02.02.10]	**Error Handling – Computational Error Notifications**	**In the event of a configurable number of consecutive Computational Errors, the Vehicle Application Component shall issue error codes to relevant external components through the applicable interface indicating that Computational Errors have occurred and that the Vehicle Application Component is operating in Degraded Mode.**		D
[1.02.02.11]	**Logging – Errors**	**The Vehicle Application Component shall log Application Level error conditions along with relevant diagnostic context of the error.**	*Detail and content of log messages is typically controlled via a configuration parameter, specifying more or less detail depending on the component's desired mode of operation.*	D
[1.02.02.12]	**GPS Position Message Handler**	**The Vehicle Application Component shall have a GPS Position Message Handler.**		D
[1.02.02.13]	**I2V Wireless Position Correction Message Initiation**	**When Lane Level Positioning Accuracy is required, the GPS Position Message Handler shall obtain I2V Wireless Position Correction Message upon initiation of the Vehicle Application Component.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.02.14]	**I2V Wireless Position Correction Message Data Delivery to GPS Receiver**	**When Lane Level Positioning Accuracy is required, the GPS Position Message Handler shall send I2V Wireless Position Correction Message Data to the GPS Positioning Unit through the Vehicle Wireless Data Systems Interface upon initiation of the Vehicle Application Component.**		D
[1.02.02.15]	**GPS Position Initiation**	**The GPS Position Message Handler shall obtain GPS Position and its accuracy from the GPS Positioning Unit through the Vehicle Wireless Data Systems Interface upon initiation of the Vehicle Application Component.**		D
[1.02.02.16]	**I2V Wireless Position Correction Message Refresh Rate**	**When Lane-Level Positioning Accuracy is required, the GPS Position Message Handler shall refresh the I2V Wireless Position Correction Message at a configurable frequency.**		D
[1.02.02.17]	**GPS Position Refresh Rate**	**The GPS Position Message Handler shall refresh the GPS Position and accuracy at a configurable frequency.**		D
[1.02.02.18]	**Map Message Handler**	**The Vehicle Application Component shall have a Map Message Handler.**		D
[1.02.02.19]	**I2V Wireless Map Message Initiation**	**The Map Message Handler shall obtain Map Data upon initiation of the Vehicle Application Component.**		D
[1.02.02.20]	**I2V Wireless Map Message Refresh Rate**	**The Map Message Handler shall refresh Map Data at a configurable frequency.**		D
[1.02.02.21]	**Single Vehicle Application**	**The Vehicle Application Component shall only provide warnings for an individual host vehicle.**	*The V2I Safety Applications are single-vehicle based and do not detect other vehicles.*	D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.02.03	**Common Vehicle Application Component Data Input Requirements**			
[1.02.03.01]	**Data – Input Validation**	**The Vehicle Application Component shall perform range and validity checks on all data inputs and shall log applicable Input Validation error messages.**		D
[1.02.03.02]	**Data – Input Validation Functional Failure**	**In the event of an Input Validation Error, the Vehicle Application Component shall not issue functional output messages to Wireless Data Systems Interface or other external components.**		D
[1.02.03.03]	**Data – Erroneous Data Disposition**	**In the event of an Input Validation Error, the Vehicle Application Component shall discard the erroneous data.**	*The Vehicle Application Component should not continue to use erroneous data in the next functional step, but may log that data for debugging purposes.*	D
[1.02.03.04]	**Data – Input Validation Error Recovery**	**In the event of an Input Validation Error, the Vehicle Application Component shall continue to process input data at the prescribed rate and continue operation.**	*The Vehicle Application Component should, to the extent possible, recover gracefully from transient error conditions and return to a normal operating condition.*	D
[1.02.03.05]	**Data – Input Validation Error Degraded Operation**	**In the event of a configurable number of consecutive Input Validation Errors, the Vehicle Application Component shall begin operating in Degraded Mode.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.03.06]	**Data – Input Validation Error Degraded Operation Notification**	**In the event of a configurable number of consecutive Input Validation Errors, the Vehicle Application Component shall issue error codes to relevant external components through the applicable interface indicating that Input Validation Error has occurred and that the Vehicle Application Component is operating in Degraded Mode.**		D
[1.02.03.07]	**Data – Input Validation Error Degraded Operation Recovery**	**In the event of a configurable number of consecutive Input Validation Errors, the Vehicle Application Component shall refresh input data and perform validity checks once per hour. In the event a configurable number of consecutive input data sets are received without Input Validation Errors, the Vehicle Application Component shall resume normal function.**	*In the event of multiple consecutive input data errors, the Application Component should enter Degraded Operational Mode in which it periodically checks for corrected input data and resumes operation upon resumption of useable input data.*	D
[1.02.03.08]	**I2V Wireless Position Correction Message Specification**	**The I2V Wireless Position Correction Message shall conform to MSG_RTCM_Corrections from SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D
[1.02.03.09]	**I2V Wireless Map Message Specification**	**The I2V Wireless Map Message shall conform to the MSG_MapData (MAP) from SAE J2735:2009-11 Dedicated Short Range Communications (DSRC) Message Set Dictionary.**		D
1.02.04	**Common Vehicle Application Component Data Output Requirements**			
[1.02.04.01]	**Data – Output Validation**	**The Vehicle Application Component shall perform range and validity checks on all data outputs and shall log applicable Output Validation error messages.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.04.02]	**Data – Erroneous Data Disposition**	**In the event of an Output Validation Error, the Vehicle Application Component shall discard the erroneous output.**	*The Vehicle Application Component should not continue to use erroneous data in the next functional step, but may log that data for debugging purposes.*	D
[1.02.04.03]	**Data – Output Validation Functional Failure**	**In the event of an Output Validation Error, the Vehicle Application Component shall not issue functional output messages to Wireless Data Systems Interface or other external components.**		D
[1.02.04.04]	**Data – Output Validation Error Recovery**	**In the event of an Output Validation Error, the Vehicle Application Component shall continue to process data at the prescribed rate and continue operation.**		D
[1.02.04.05]	**Data – Output Validation Error Degraded Operation**	**In the event of a configurable number of consecutive Output Validation Errors, the Vehicle Application Component shall begin operating in Degraded Mode.**		D
[1.02.04.06]	**Data – Output Validation Error Degraded Operation Notification**	**In the event of a configurable number of consecutive Output Validation Errors, the Vehicle Application Component shall issue error codes to relevant external components through the applicable interface indicating that Input Validation Error has occurred and that the Vehicle Application Component is operating in Degraded Mode.**		D
1.02.05	**Common Vehicle Application Component Computation and Communication Performance Requirements**			
[1.02.05.01]	**Operational Hardware Resources**	**The Vehicle Application Component shall function using interfaces available on the Vehicle Application Platform.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.05.02]	Application Processing Speed	The Vehicle Application Component shall perform the functions described under Vehicle Application Functional Requirements at a frequency of at least 10 Hz.		D
[1.02.05.03]	Vehicle Data Systems Vehicle Speed Accuracy	Vehicle Data Systems speed data shall be accurate to within 1 meter per second.		D
1.02.06	**Common Vehicle Application Component Operational Performance Requirements**			
[1.02.06.01]	Vehicle Classes and Types	The Vehicle Application Component shall meet its functional requirements on vehicle classes and types on which it will be deployed.		D
[1.02.06.02]	Roadway Classes	The Vehicle Application Component shall meet its functional requirements on the functional classes of roadway and levels of service (LOS) on which it is deployed. "Highway Functional Classification: Concepts, Criteria and Procedures", FHWA-PL-13-026 and AASHTO's "A Policy on Geometric Design of Highways and Streets", AASHTO, 2001 are referenced for guidance.		D
[1.02.06.03]	Roadway Geometry	The Infrastructure Application Component shall meet its functional requirements on road geometries on which it will be deployed. AASHTO's "A Policy on Geometric Design of Highways and Streets", AASHTO, 2001 is referenced for guidance.		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.02.07	**Common Vehicle Application Component Supportability Requirements**			
[1.02.07.01]	**Interoperability, Interchangeability, Compatibility and Maintainability (Software)**	**The Vehicle Application Component shall communicate with external components through Vehicle Application Platform Interfaces.**		D
[1.02.07.02]	**Modularity (Software)**	**The software architecture of the Infrastructure Application Component shall be organized to co-exist with multiple, independent Vehicle Application Components on the Vehicle Application Platform without conflict or interference.**		D
[1.02.07.03]	**Portability (Software)**	**The Vehicle Application Component should be designed such that platform-dependent code is identified and encapsulated wherever and whenever performance considerations permit.**		A
1.02.08	**Common Vehicle Application Component Security Requirements**			
[1.02.08.01]	**Access Control**	**Access to modify the Vehicle Application Component and its configuration, data and log files, shall be restricted to personnel authorized by the Application Owner.**		D
1.02.09	**Common Vehicle Application Component Human Factors, Health and Safety Requirements**			
[1.02.09.01]	**Safety**	**The Vehicle Application Component shall not issue inaccurate messages to drivers during installation, configuration, operation, or diagnostics.**	*The application must not create a safety hazard during installation, configuration, operation, or diagnostics.*	A

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.09.02]	**Driver Capabilities**	**The V2I Safety Vehicle Application Component shall support the physical and cognitive capabilities of drivers qualified to obtain a driver's license. Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Sanquist, T., Bacon, L. P., … Morgan, J. F. (in press). Driver Vehicle Interface (DVI) Design Assistance for Advanced Technology Applications. (Final report to Virginia Tech Transportation Institute and National Highway Traffic Safety Administration). Seattle, WA: Battelle, is referenced for guidance.**		A
[1.02.09.03]	**Driver Customization**	**The Vehicle Application Component shall not be customized for individual drivers or classes of drivers or driving characteristics.**	*Future implementations may be customized for individual drivers or classes of drivers or driving characteristics.*	D
1.02.10	**Common Vehicle Application Component Installation and Setup Requirements**			
[1.02.10.01]	**Installing and Maintaining Software**	**The Vehicle Application Component shall support installation and maintenance by authorized entitles.**		D
1.02.11	**Common Vehicle Application Component Operation, Maintenance and Diagnostic Requirements**			
[1.02.11.01]	**Function – Self-Diagnostics**	**The Vehicle Application Component shall perform self-diagnostics upon power up and at configurable periodic intervals.**		D
[1.02.11.02]	**Operational Mode – Determination**	**The Vehicle Application Component shall determine the operating level/mode of operation based on the results of software errors and/or self-diagnostic tests of the application and self-diagnostic tests of the Vehicle Application Platform.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.11.03]	**Operation Mode – Required Modes**	**The Infrastructure Application Component shall support the following operational modes:** **Full Operation (Online)** **Degraded Operation (Online)** **Failed (Offline)** **Diagnostic Operation (Offline)**	*Operational Modes are determined through self diagnostics and error handling.* *Degraded Operation – Result of partial failure, such as failure of an input data validity check or failure of one or more of the data input or output interfaces, that supports partial operation only. Partial operation may include examples such as the ability to issue Driver Infrastructure Interface messages only, the ability to send I2V communication messages only.*	D
[1.02.11.04]	**Full Operation Mode Criterion**	**The Vehicle Application Component shall maintain (or restore) itself in Full Operation when self-diagnostic tests are passed.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.11.05]	**Degraded Mode Criterion**	**The Vehicle Application Component shall operate in Degraded Mode in the event of a partial failure.**	*Examples of partial failure include failure of an input data validity check or failure of one or more of the data input or output interfaces, such as the ability to issue messages only to the Driver Warning System or only to Wireless Data Systems. Partial operation may include examples that prevent the application from processing data and from issuing any message or output, other than default advisory, caution or error messages.*	D
[1.02.11.06]	**Failed Mode Criterion**	**The Vehicle Application Component shall enter Failed-Offline Mode and cease issuing messages in the event of an error and/or self-diagnostic failure or any event that prevents the application from issuing accurate messages to other system components.**		D
[1.02.11.07]	**Diagnostic Mode Criterion**	**The Vehicle Application Component shall have a Maintenance and Diagnostic mode to support installation, operation, and diagnostics of the Vehicle Application Components through a maintenance interface.**		D
[1.02.11.08]	**Degraded or Failed Status Reporting**	**Where necessary to ensure vehicle and roadway safety, the Vehicle Application Component shall communicate degraded or failed status to the Vehicle Wireless Data Systems and the Driver Warning System.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.02.11.09]	**Logging – Error and Diagnostic Data**	**The Vehicle Application Component shall log self-diagnostic test information which contains, at a minimum, the following information:** **1. Operational Mode and Online/Offline status** **2. Self-diagnostic test information** **a. Date and time of test** **b. Test performed** **c. Result of test (Pass/Fail)** **d. Actions resulting from Failed Test** **e. Relevant diagnostic and maintenance data to support debugging.**		D
[1.02.11.10]	**Logging – Diagnostic Data**	**The Vehicle Application Component shall log all errors and relevant diagnostic and maintenance data to support debugging.**		D
[1.02.11.11]	**Logging – Error and Diagnostic Data Logging Retention**	**The Vehicle Application Component shall maintain historical information of self-diagnostic tests for a configurable period in non-volatile storage.**	*Non-volatile storage refers to storage that remains intact even when there is no power. (It is left up to the implementer to determine if the retention of data is a fixed window of time or if it is based on a fixed amount of storage.)*	D
[1.02.11.12]	**Logging – Diagnostic Data Storage Overflow**	**If diagnostic data exceeds available memory resources, records shall be overwritten on a first in/first out basis.**		D

Table 3-2. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.02.12	**Common Vehicle Application Component Documentation Requirements**			
[1.02.12.01]	**User Manual Documentation**	**The Vehicle Application Component shall include online Technical User Manual which includes, at a minimum, the following information:** **- Design and Functions of the Vehicle Application Component** **- Specifications for Interfaces** **- Specifications for Messages Input to and Output from the Vehicle Application Component** **- Error codes and error messages and relevant troubleshooting and diagnostic Information** **- Instructions for installation, operation, and diagnostics for the Vehicle Application Component**		I
1.02.13	**Common Vehicle Application Component Staffing and Training Requirements**			
[1.02.13.01]	**Training Material Documentation**	**The Vehicle Application Component shall include online training materials for installation, operation, and diagnostics procedures for the Component.**		I

3.3.3 Infrastructure Application Platform Performance Requirements

Table 3-3 catalogs the recommended Infrastructure Application Platform Performance Requirements. These were developed based upon the V2I Functional Architecture in Figure 3-1 and the integration strategy described for each of the applications. It is expected that, as connected vehicle technology evolves and vehicle and infrastructure application component owners develop V2I Safety Applications, the rationales, frameworks, and performance requirements presented here will evolve. Accordingly, before embarking upon design and development, application owners should update and refine the requirements to reflect current standards and policies. It is the responsibility of the designer to ensure that the resulting applications do not conflict with applicable published state and national regulations, policies, and guidelines.

Table 3-3. Common Vehicle Application Component Performance Requirements

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.03	**Common Infrastructure Application Platform Requirements**			
1.03.01	**Common Infrastructure Application Platform Interfaces and Interface Specifications**			
[1.03.01.01]	**GPS Interface**	**The Infrastructure Application Platform shall have an interface to a UTC Time Source.**	*The Infrastructure Application Platform time source must be the same as that of nearby vehicles to support time synchronization of infrastructure and vehicle applications. This requirement may be satisfied through a GPS receiver. The Infrastructure Application Components are not expected to require the latitude, longitude and elevation of the Platform.*	D
[1.03.01.02]	**Infrastructure Wireless Data Systems Interface**	**The Infrastructure Application Platform shall have an Infrastructure Wireless Data Systems Interface.**	*Infrastructure and Vehicle Application Components exchange messages wirelessly through Wireless Data Systems and the V2I/I2V Wireless Data Interface.*	D
[1.03.01.03]	**Infrastructure Wireless Data Systems Interface Specifications**	**The Infrastructure Wireless Data Systems Interface shall implement secure exchange of SAE J2735:2009-11 messages.**	*Infrastructure and Vehicle Application Components exchange messages using the SAE J2735 message set.*	D
[1.03.01.04]	**Environmental Sensor Stations (ESS) Interface**	**When the Infrastructure Application Platform will support V2I Safety Applications which obtain data from local Environmental Sensor Stations (ESS), the Infrastructure Application Platform shall have an ESS interface.**	*Supports V2I Safety Applications that are implemented in conjunction with Environmental Safety Stations. These applications may include Curve Speed Warning (CSW), Spot Weather Information Warning – Reduced Speed (SWIW-RS), and Spot Weather Information Warning – Diversion (SWIW-D).*	D

Table 3-3. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.03.01.05]	**Environmental Sensor Stations (ESS) Interface Specifications**	**Each ESS Interface shall implement NTCIP 1204 v03 Object Definitions for Environmental Sensor Stations (ESS) Standard.**		D
[1.03.01.06]	**Vehicle Speed Sensor Systems Interface**	**When the Infrastructure Application Platform will support V2I Safety Applications which obtain data from local Infrastructure-based Vehicle Speed Sensor Systems, the Infrastructure Application Platform shall have a Vehicle Speed Sensor Systems Interface.**	*Supports V2I Safety Applications that are implemented in conjunction with local Vehicle Speed Sensors. These applications may include Curve Speed Warning (CSW), Spot Weather Information Warning – Reduced Speed (SWIW-RS), and Stop Sign Gap Assist.*	D
[1.03.01.07]	**Vehicle Speed Sensor Systems Interface Specifications**	**Each Vehicle Speed Sensor Systems Interface shall implement NTCIP 1209 v02 Object Definitions for Transportation Sensor Systems (TSS).**		D
[1.03.01.08]	**Traffic Signal Controller Interface**	**When the Infrastructure Application Platform will support V2I Safety Applications which obtain data from local Traffic Signal Controllers, the Infrastructure Application Platform shall have a Traffic Signal Controller interface.**	*Supports V2I Safety Applications that are implemented in conjunction with Traffic Signal Controllers. These applications may include Red Light Violation Warning (RLVW).*	D
[1.03.01.09]	**Traffic Signal Controller Interface Specifications 1**	**Each Traffic Signal Controller interface shall implement NTCIP 1202:2005 V02.19 Object Definitions for Actuated Traffic Signal Controllers (ASC) Standard.**		D

Table 3-3. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.03.01.10]	**Traffic Signal Controller Interface Specifications 2**	**Each Traffic Signal Controller interface shall implement NTCIP 1211:2008 V01.38 Object Definitions for Signal Control and Prioritization (SCP) Standard.**		D
[1.03.01.11]	**Dynamic Roadside Signage Interface**	**When the Infrastructure Application Platform will support V2I Safety Applications which send data to local Dynamic Message Signs, the Infrastructure Application Platform shall have a Dynamic Message Sign Interface.**		D
[1.03.01.12]	**Dynamic Roadside Signage Interface Specifications**	**Each Dynamic Roadside Signage interface shall implement NTCIP 1203 v02 Object Definitions for Dynamic Message Signs (DMS) Standard.**		D
[1.03.01.13]	**Local/Back Office Local User Interface**	**The Infrastructure Application Platform shall have a TIA/EIA-568 8P8C (Ethernet port) for local systems interface for the secure exchange of IP data between the Platform and a locally connected computer.**		D
[1.03.01.14]	**Local/Back Office User Interface**	**The Infrastructure Application Platform shall secure communications of Internet Protocol data between the Platform and a Back Office User Interface.**		D
[1.03.01.15]	**Configurable Back Office Communication**	**The Infrastructure Application Platform shall be able to be configured at installation to communicate to a back office system.**	*V2I Applications may be installed in locations with or without communications connectivity to a back office.*	D

Table 3-3. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
1.03.02	**Common Infrastructure Application Platform Functional Requirements**			
[1.03.02.01]	**Platform Specification**	**The Infrastructure Application Platform shall conform to Institute for Transportation Engineers (ITE) ATC Transportation Controller Standard v05.2b.**		D
[1.03.02.02]	**Processing Hardware Resources**	**The Infrastructure Application Platform computational processor speed shall be at least 1.25 times the speed required by the installed application(s).**		A
[1.03.02.03]	**Memory Resources**	**The Infrastructure Application Platform shall have at least 1.25 times the dynamic memory resources required by the installed application(s).**		A
[1.03.02.04]	**Onboard Storage Resources**	**The Infrastructure Application Platform shall have at least 1.5 times the nonvolatile data storage resources required by the installed application(s).**		A
[1.03.02.05]	**Configuration, data and log file storage**	**The Infrastructure Application Platform shall persistently store configuration, data and log files for each installed application.**		D
[1.03.02.06]	**System Time Standard**	**The Infrastructure Application Platform shall conform to the Universal Time, Coordinated (UTC) standard.**		D
[1.03.02.07]	**Common Time Source**	**The Infrastructure Application Platform shall supply a common time to all Infrastructure Application Components.**		D

Table 3-3. Common Vehicle Application Component Performance Requirements (Continued)

Rqmt. No.	Requirement Title	Performance Requirement	Elaboration	Verif. Method (I,D,T,A)
[1.03.02.08]	**Security Protocols**	**The Infrastructure Application Platform shall implement Security Protocols in accordance in the current version of NTCIP 1103 Transportation Management Protocols.**		D
[1.03.02.09]	**Logging Service**	**The Infrastructure Application Platform shall provide a logging service for use by all installed applications.**		D
[1.03.02.10]	**I2V Wireless Position Correction Message Input Specification**	**The I2V Wireless Position Correction Message GPS Differential Correction input data shall conform to Radio Technical Commission for Maritime Services (RTCM) 10402.3.**		D

APPENDIX A. MUTCD Guidance Relevant to Selected Connected Vehicle V2I Safety Applications

A.1 Introduction

The purpose of the connected vehicle V2I safety applications is to provide more robust and reliable advisory, alert, and warning messages 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. These applications are intended to enhance safety and driver information by supplementing existing signage on the roadside via dynamic DII signage and in the vehicle via a DVI. These application advisory, alert, and warning messages are largely expected to consist of visual text and symbols. As such, it is expected that current signage standards may be used, adapted, and expanded to incorporate the messages necessary to successfully convey the recommended application advisory, alert, or warning message. Specifically, the connected vehicle V2I safety applications covered in this appendix include Curve Speed Warning (CSW), Red Light Violation Warning (RLVW), Reduced Speed Zone Warning with Lane Closure (RSZW/LC), Spot Weather Information Warning – Reduced Speed (SWIW-RS), Spot Weather Information Warning – Diversion (SWIW-D), and Stop Sign Gap Assist (SSGA).

The MUTCD is recognized as the national standard for all traffic control devices on any roadway open to public travel. Traffic control devices are defined by the MUTCD as “all signs, signals, markings, and other devices used to regulate, warn, or guide traffic, placed on, over, or adjacent to a street, highway, pedestrian facility, bikeway, or private road open to public travel”. The MUTCD was initially created due to a recognized need for uniform standards nationally for traffic control devices to promote highway safety and efficiency.

The MUTCD provides a variety of guidance, including information relevant to design, placement, operations, maintenance, and authority for placement of traffic control devices. Additionally, the MUTCD provides guidance for the application of signage. Generally, an engineering study or engineering judgment is employed in the determination of placement of traffic control devices. In particular for traffic signals, a set of eight warrants establish criteria for an analysis of factors to justify installation. These criteria examine existing operation and safety at a location to determine the potential for improvement by a traffic signal. Similar guidance could be used for identifying candidate locations for the installation of infrastructure to support a connected vehicle V2I safety application.

Although the MUTCD is a national standard, it acknowledges continuing advances in technology and the importance of updating, allowing for a relatively quick evolution and updating process based on sound research and experimentation. Procedures are specified in the MUTCD to request permission to experiment and receive interim approval from FHWA for traffic control devices. If granted the permission to experiment, an on-going evaluation is conducted on the experimental traffic control device, and following successful experimentation, revisions to the MUTCD may be requested to include additions or changes based on these findings. Similar processes may be required for the placement and use of dynamic message signs (DMS) as a DII for certain advisory, alert, and warning messages to drivers from the V2I safety applications.

The remainder of this appendix highlights several topics that are found in the MUTCD that are likely to be most relevant for the deployment of V2I safety applications. Specifically, the next section discusses the use of DMS, followed by sections on advisory speed determination and placement, advanced placement of warning signs, the need for signs, temporary traffic control, and specific signage within the MUTCD that could be used for the V2I safety applications.

A.2 Use of Dynamic Message Signs

Guidance on the use of changeable message signs (CMS), which are also known as DMS, are discussed in Chapter 2L of the MUTCD. The use of DMS for V2I safety applications is approved by the MUTCD, as these applications include their use for incident management and route diversion, warning of adverse weather conditions, control at crossing situations, warning situations, and speed control.

Messages displayed on DMS may be only text or may also contain symbols. Restrictions on the lengths of messages and units of information to display in a message are given. A unit of information answers questions such as “what happened?”, “where?”, etc., and no more than three units of information can be used per phase and no more than four or five total units of information for speeds greater or less than 35 mph, respectively. Specifically, messages can be no longer than two phases, each phase consisting of no more than three lines of text. Messages are not to include fading, rapid flashing, exploding, dissolving, moving, or scrolling messages.

The MUTCD also contains guidance regarding the design, legibility, and visibility of DMS, including the need for them to automatically adjust their brightness under varying light conditions, size and spacing of characters, colors to be used for legends and backgrounds, and installation of permanent DMS.

Several DMS standards related to placement are particularly relevant the V2I safety applications. DMS are to be located sufficiently upstream of known bottlenecks, high crash locations, and major diversion routes to allow drivers to change lanes, select an alternate route, etc. DMS are not to be placed in locations with an already high information load on drivers because of other guide signs and other information, nor in areas where lane-changing maneuvers or merging and weaving conditions exist; this latter guidance could impact the placement of DMS for use in the SSGA application.

A.3 Advanced Placement of Warning Signs

Table A-1 below comes directly from MUTCD Section 2C.04 and provides guidelines for the advance placement of warning signs. This guidance can likely inform the placement of DII signage and/or timing for the issuance of messages from a DVI prior to the crash-immenent scenario for several V2I safety applications that, i.e., CSW, RLVW, and RSZW/LC. The first column of Table A-1 lists posted or 85^{th}-percentile speeds on the roadway (whichever is higher on the roadway is to be used), by which to establish the distance for placing advance warning signs. The second column, “Condition A” would pertain to certain types of deployments of the RSZW/LC application when a lane shift is required. The third column, “0” might apply to the RLVW application for advanced warning when a stop will be required at a signalized intersection. The remaining columns would pertain to both RSZW/LC and CSW applications.

Table A-1. MUTCD Guidelines for Advance Placement of Warning Signs

Posted or 85th-Percentile Speed	Advance Placement Distance[1]								
	Condition A: Speed reduction and lane changing in heavy traffic[2]	Condition B: Deceleration to the listed advisory speed (mph) for the condition							
		0[3]	10[4]	20[4]	30[4]	40[4]	50[4]	60[4]	70[4]
20 mph	225 ft	100 ft[6]	N/A[5]	—	—	—	—	—	—
25 mph	325 ft	100 ft[6]	N/A[5]	N/A[5]	—	—	—	—	—
30 mph	460 ft	100 ft[6]	N/A[5]	N/A[5]	—	—	—	—	—
35 mph	565 ft	100 ft[6]	N/A[5]	N/A[5]	N/A[5]	—	—	—	—
40 mph	670 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	—	—	—	—
45 mph	775 ft	175 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	—	—	—
50 mph	885 ft	250 ft	200 ft	175 ft	125 ft	100 ft[6]	—	—	—
55 mph	990 ft	325 ft	275 ft	225 ft	200 ft	125 ft	N/A[5]	—	—
60 mph	1,100 ft	400 ft	350 ft	325 ft	275 ft	200 ft	100 ft[6]	—	—
65 mph	1,200 ft	475 ft	450 ft	400 ft	350 ft	275 ft	200 ft	100 ft[6]	—
70 mph	1,250 ft	550 ft	525 ft	500 ft	450 ft	375 ft	275 ft	150 ft	—
75 mph	1,350 ft	650 ft	625 ft	600 ft	550 ft	475 ft	375 ft	250 ft	100 ft[6]

[1] The distances are adjusted for a sign legibility distance of 180 feet for Condition A. The distances for Condition B have been adjusted for a sign legibility distance of 250 feet, which is appropriate for an alignment warning symbol sign. For Conditions A and B, warning signs with less than 6-inch legend or more than four words, a minimum of 100 feet should be added to the advance placement distance to provide adequate legibility of the warning sign.

[2] Typical conditions are locations where the road user must use extra time to adjust speed and change lanes in heavy traffic because of a complex driving situation. Typical signs are Merge and Right Lane Ends. The distances are determined by providing the driver a PRT of 14.0 to 14.5 seconds for vehicle maneuvers (2005 AASHTO Policy, Exhibit 3-3, Decision Sight Distance, Avoidance Maneuver E) minus the legibility distance of 180 feet for the appropriate sign.

[3] Typical condition is the warning of a potential stop situation. Typical signs are Stop Ahead, Yield Ahead, Signal Ahead, and Intersection Warning signs. The distances are based on the 2005 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT of 2.5 seconds, a deceleration rate of 11.2 feet/second^2, minus the sign legibility distance of 180 feet.

[4] Typical conditions are locations where the road user must decrease speed to maneuver through the warned condition. Typical signs are Turn, Curve, Reverse Turn, or Reverse Curve. The distance is determined by providing a 2.5 second PRT, a vehicle deceleration rate of 10 feet/second^2, minus the sign legibility distance of 250 feet.

[5] No suggested distances are provided for these speeds, as the placement location is dependent on site conditions and other signing. An alignment warning sign may be placed anywhere from the point of curvature up to 100 feet in advance of the curve. However, the alignment warning sign should be installed in advance of the curve and at least 100 feet from any other signs.

[6] The minimum advance placement distance is listed as 100 feet to provide adequate spacing between signs.

Source: MUTCD

A.4 Locations that Require Signs

A.4.1 CSW

The MUTCD requires placement of horizontal alignment warning signs on all freeways, and on select arterials and collectors with over 1000 annual average daily traffic (AADT) based on the speed differential between the curve advisory speed and either: 1) the posted or legal speed limit or 85th percentile speed, whichever is higher, or 2) the prevailing speed on the approach to the curve. Table A-2 shows selected horizontal alignment signs that are recommended or required for those situations based on the speed differential. The types of horizontal alignment signs are described in Section A.7.1 of this appendix.

Table A-2. Required and Recommended Placement of Horizontal Alignment Signs

Type of Horizontal Alignment Sign	Difference Between Speed Limit and Advisory Speed				
	5 mph	10 mph	15 mph	20 mph	25 mph or more
Turn (W1-1), Curve (W1-2), Reverse Turn (W1-3), Reverse Curve (W1-4), Winding Road (W1-5), and Combination Horizontal Alignment/Intersection (W10-1) (see Section 2C.07 to determine which sign to use)	Recommended	Required	Required	Required	Required
Advisory Speed Plaque (W13-1P)	Recommended	Required	Required	Required	Required

Source: MUTCD

Optionally as described in MUTCD Section 2C.13, a truck rollover warning sign can be used in curves where an engineering study has determined that geometric conditions could contribute to a loss of control or rollover. This engineering study could include an accelerometer providing a direct determination of side friction factors, a design speed equation, or a traditional ball-bank indicator using 10 degrees of ball bank. If used, the MUTCD requires a truck rollover sign be used with an advisory speed plaque to recommend speeds to those vehicles. Further, the MUTCD also includes a provision to display this sign as a DMS activated by the detection of an approaching vehicle with a high center of gravity that is traveling in excess.

A.4.2 RLVW

The MUTCD offers guidance on when to install advanced warning signs for a signalized intersection, which is relevant to the RLVW application. The placement of advanced warning signs is required for a signalized intersection based on minimum sight distance for visibility of the traffic signals, i.e., if the signal is not visible then an advanced warning sign is required. Advanced warning signs for a signalized intersection may be placed even if the visibility distance is satisfactory.

A.4.3 RSZW/LC

The MUTCD recommends placement of reduced speed limit ahead signs whenever the speed limit is being lowered by more than 10 mph, or when engineering judgment indicates the need for advance notice for the driver to comply with the lowered posted speed limit.

MUTCD Section 6C.04 includes guidance on the placement of signage in a temporary traffic control zone in the advance warning area. There are no specific requirements for a temporary traffic control zone as work zones are unique and conditions are expected to vary significantly. However, the MUTCD notes that reduced speed limits should only be used in the specific part of the work zone where conditions or restrictive features are present without causing frequent changes in the speed limit. The MUTCD discourages the lowering of speed limits, however if necessary, it recommends against lowering the speed limit more than 10 mph.

Regarding reduced speeds for school zones, MUTCD Chapter 7B includes reduced speed limit sign guidance for the purpose of standardization, however it does not specifically endorse or require mandatory reduced speed zones near schools. Guidance for the placement of signs for a reduced school speed limit zone is in accordance with general advanced placement guidelines.

A.4.4 SWIW-RS

The MUTCD does not provide any specific recommendations for the placement of weather-related signage. Instead, the provision of surface condition signs (MUTCD Section 2C.32) and weather condition signs (MUTCD Section 2C.35) are optional for areas where those conditions are frequently present.

A.4.5 SWIW-D

The MUTCD does not provide specific recommendations for the placement of signage for weather-related road closures. However, general guidance includes standards for the placement of road closed signage (MUTCD Section 2B.58). The MUTCD also discusses the usage of appropriate advanced warning and detour signing.

A.4.6 SSGA

Regarding the SSGA application, guidance exists for the design of a stop-controlled intersection, but there is no specific guidance for providing information to drivers on the minor road for when to not proceed. Chapter 4 discusses highway traffic signals, including guidance and alternatives for replacing a stop sign with traffic signals. These traffic control signal needs studies might provide some parameters for the introduction of a SSGA application at a stop-controlled intersection, either as an alternative to a traffic signal or when treatment is needed, but a traffic signal is not warranted.

A.5 Advisory Speed Determination and Placement

Three V2I safety applications could issue advisory speeds or reduced enforceable speed limits given current conditions: the CSW, RSZW/LC, and SWIW applications. The MUTCD offers guidance on the provision of advisory speeds for curves, including the location to place the sign and the actual advisory speed that should be posted based on the curve geometry and posted speed limit. The MUTCD also allows for the placement of advisory speeds in temporary traffic control situations (MUTCD Section 6F.52), although no specific guidance is given and would likely be a part of the unique plans for each work zone.

A.5.1 CSW

The MUTCD has a number of standards related to the placement of advisory speed plaques for curves, including exit ramps (MUTCD Section 2C.10) and truck rollover situations (MUTCD Section 2C.13). Typically these advisory speed plaques are to be used in combination with and as a supplement to other warning signs. Alternatively, the advisory speed may actually be a part of a larger warning sign, such as those used for an exit ramp (MUTCD Section 2C.14).

Advisory speeds to be displayed are required to be multiples of 5 mph, and only as determined by an engineering study (except in emergencies or temporary situations). The engineering study may be based on an accelerometer that provides a direct determination for side friction factors, a design speed equation, or a traditional ball-bank indicator (16 degrees of ball-bank for speeds of ≤20 mph, 14 degrees for 25-30 mph, and 12 degrees for ≥35 mph). These MUTCD recommendations are similar to AASHTO horizontal curve design guidance.

The MUTCD offers guidance to say that the advisory speed should be based on free-flowing traffic conditions. Because site condition changes can affect the advisory speed, each location should be evaluated periodically or when roadway geometrics, surface characteristics, sight distance, or other conditions change. The MUTCD notes that research has shown that drivers often exceed posted advisory curve speeds by 7-10 mph.

A.6 Temporary Traffic Control

Part 6 of the MUTCD is devoted entirely to temporary traffic control. The MUTCD acknowledges that the information presented is not intended to be comprehensive, but simply present typical applications of temporary traffic control devices. Although this part of the MUTCD applies to temporary traffic control primarily as it pertains to work zones and the RSZW/LC application, this guidance might also be used for temporary traffic control due to weather conditions and thus be relevant to SWIW application as well, e.g., recommending detours.

In addition to information already presented in previous sections of this appendix, MUTCD Part 6 offers guidance on the components of a temporary traffic control zone, which are the advanced warning area upstream of the work zone, the transition area for lane closures and lane shifts, the work zone activity area itself, and the termination area where normal traffic operations resume. These sections include standards on the types, design, and placement of markings and signage, as well as taper length criteria and stopping sight distance criteria.

While Part 6 of the MUTCD includes recommendations for typical applications, it is expected that this information will primarily be used to assist in the overarching vision for the RSZW/LC application. Specific details on geometry and spacing is expected to vary for each individual work zone, and will be provided as unique inputs for each RSZW/LC application deployment. Guidelines for the spacing of advanced warning signs for various roadways are presented in Table A-3.

Table A-3. MUTCD-recommended Advance Warning Sign Minimum Spacing

Road Type	Distance Between Signs**		
	A	B	C
Urban (low speed)*	100 feet	100 feet	100 feet
Urban (high speed)*	350 feet	350 feet	350 feet
Rural	500 feet	500 feet	500 feet
Expressway / Freeway	1,000 feet	1,500 feet	2,640 feet

* Speed category to be determined by the highway agency
** The column headings A, B, and C are the dimensions shown in Figures 6H-1 through 6H-46. The A dimension is the distance from the transition or point of restriction to the first sign. The B dimension is the distance between the first and second signs. The C dimension is the distance between the second and third signs. (The "first sign" is the sign in a three-sign series that is closest to the TTC zone. The "third sign" is the sign that is furthest upstream from the TTC zone.)

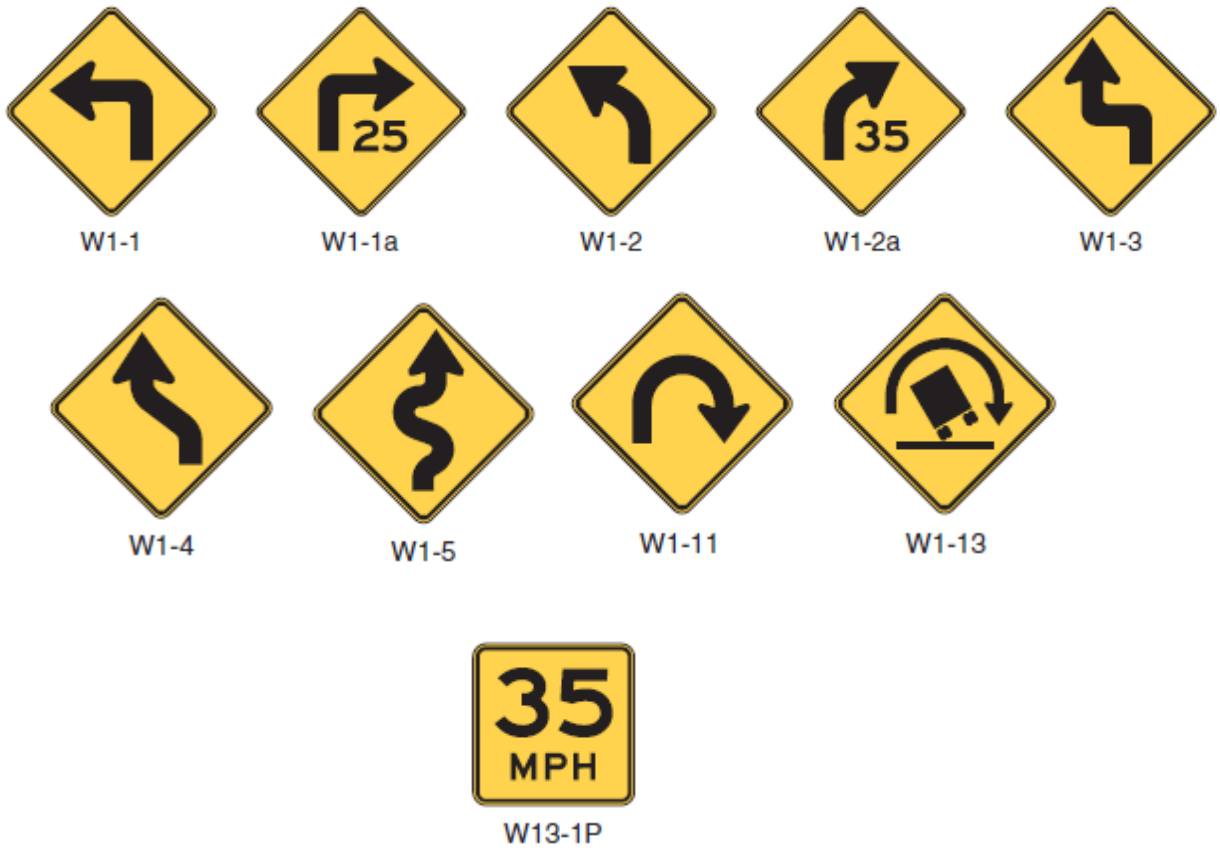
Source: MUTCD

A.7 MUTCD-approved Sign Options for Applications

The MUTCD includes figures of approved signs to indicate the appropriate symbols, colors, and shapes to use in given situations. Select signs that may be relevant for the V2I safety applications are presented below, including the MUTCD reference number for the sign. It is possible that a use of the symbol or text may be applied differently or be modified for the V2I safety applications than is currently recommended, thus experimentation may be required. The signs presented below are not an all-inclusive list, but are intended to be a foundation on which to build a message set for DII and DVI use in the V2I safety applications.

A.7.1 CSW

Figure A-1 shows signs that may be relevant for the CSW application. In most instances with static signs, a horizontal alignment symbol is given for a curve, S-curve, or longer series of curves and a supplemental advisory speed plaque (i.e., W13-1P) is added beneath. However, there are signs that include the symbol and advisory speed on the same sign (i.e., W1-1a and W1-2a). A sign is also available specifically to indicate rollover conditions (W1-13).



Source: Battelle

Figure A-1. Selected Horizontal Alignment Signs and Plaques from the MUTCD

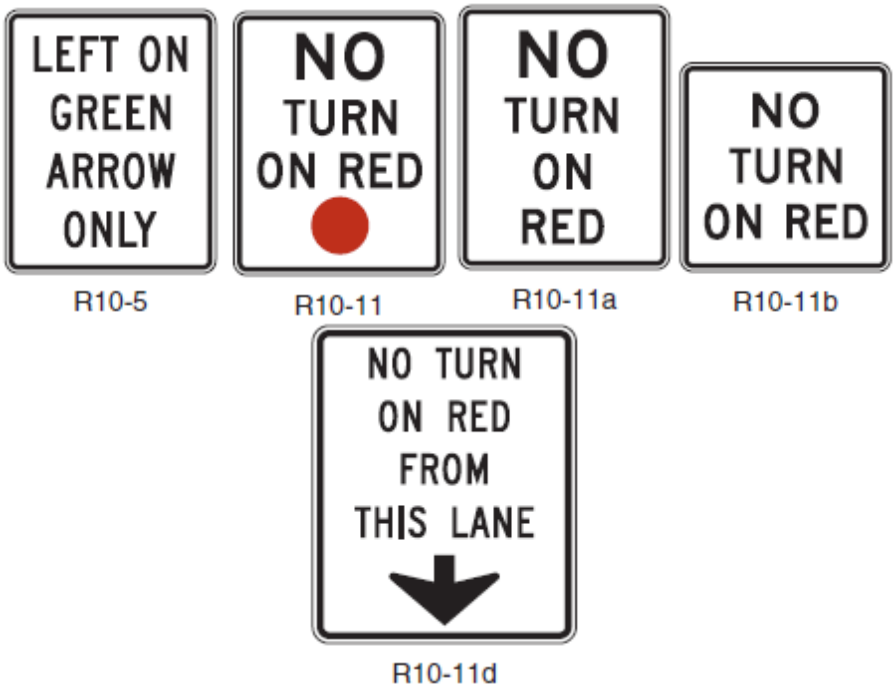
A.7.2 RLVW

There are two sets of signs from the MUTCD that may be relevant for the RLVW application. First, for vehicles approaching an intersection, Figure A-2 shows two signage standards for vehicles approaching a signalized intersection.

Source: Battelle

Figure A-2. Select Signs from the MUTCD for Vehicles Approaching a Signalized Intersection

Figure A-3 shows a series of signs from the MUTCD that may be relevant for vehicles at the stop bar waiting for a green light. The RLVW application may issue a warning for vehicles that have come to a complete stop, but are determined to be entering the intersection during a red light. If local policy is known, an advisory, alert, or warning issue could be issued by the RLVW application DVI if the vehicle is thought to be entering the intersection when such an action is prohibited.



Source: Battelle

Figure A-3. Select Signs from the MUTCD for Vehicles at a Signalized Intersection

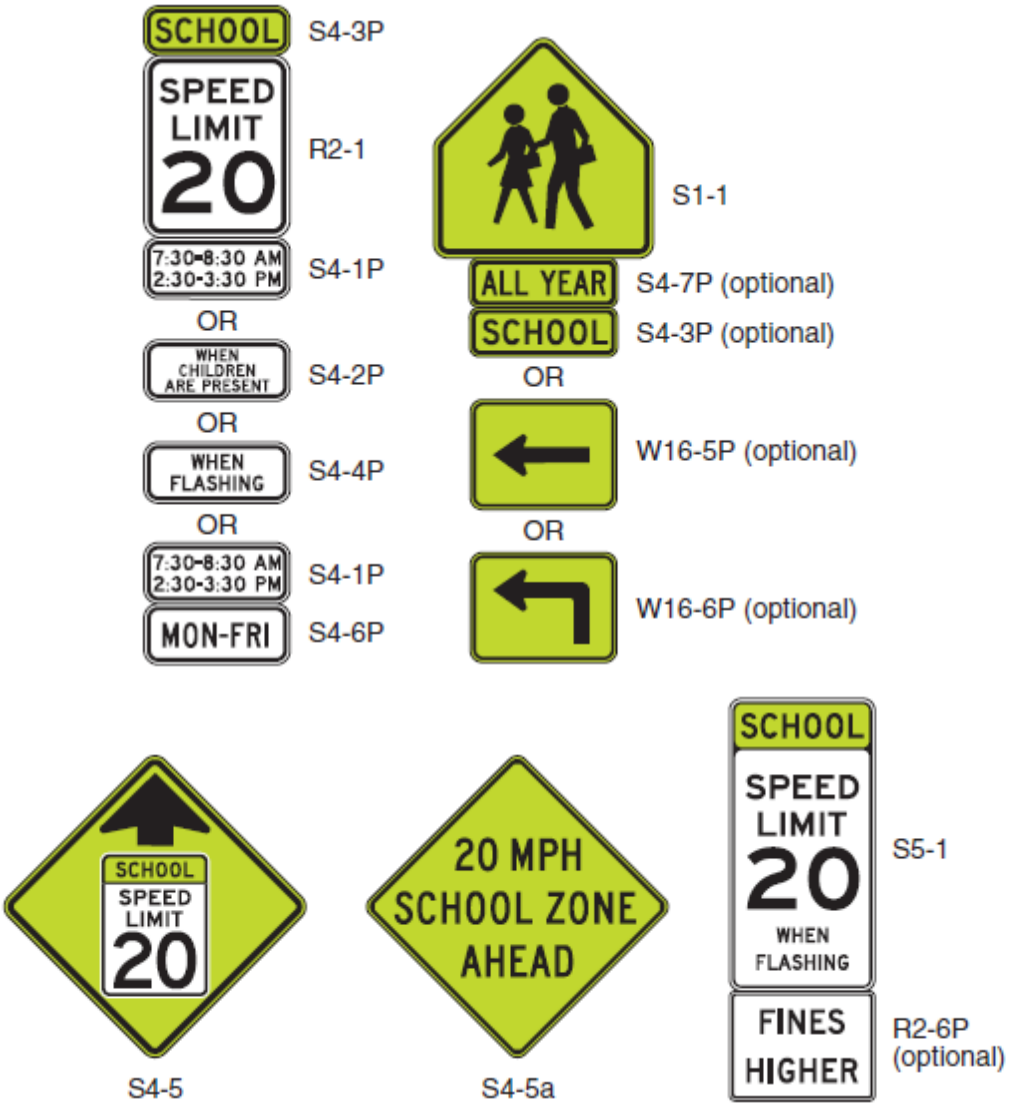
A.7.3 RSZW/LC

There are a variety of signs from the MUTCD that could be utilized in the RSZW/LC application, depending on the type of reduced speed zone. For a location where there is a general reduction in speed, e.g., at a city boundary, signs such as those in Figure A-4 might be employed by the RSZW/LC application.

Source: Battelle

Figure A-4. Select Signs from the MUTCD to Indicate a Reduction in the Speed Limit Ahead

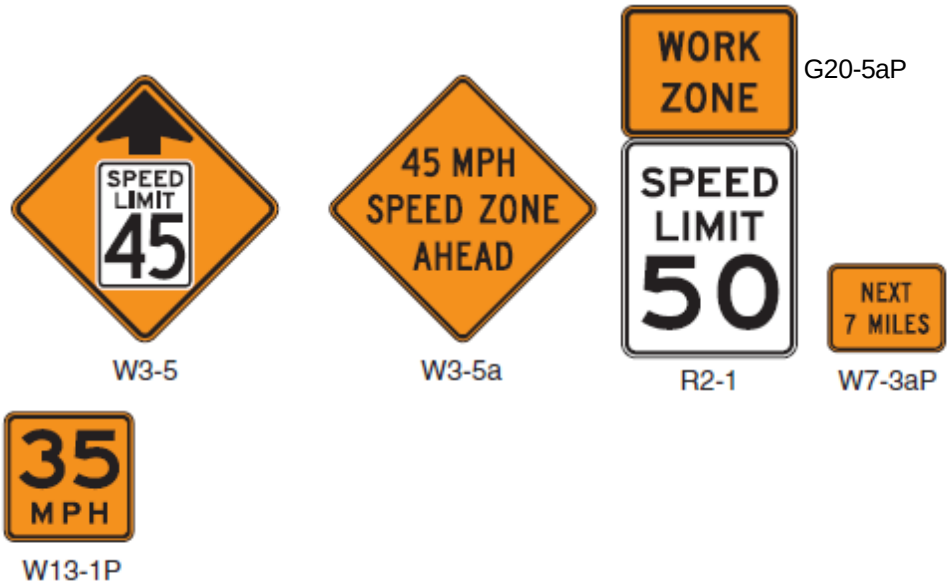
For a location where the reduced speed is due to a school zone, the MUTCD-recommended signs shown in Figure A-5 could be guide development of messages for the RSZW/LC application.



Source: Battelle

Figure A-5. Select Signs from the MUTCD to Indicate a Reduction in the Speed Limit due to a School Zone

If the reduction speed is due to a work zone, a variety of signs are provided in the MUTCD, as shown in Figure A-6, including a plaque (i.e., W7-3aP) to indicate the length of the work zone for which the primary sign is applicable. A second plaque (i.e., W13-1P) can be used to provide a recommended advisory speed in conjunction with a work zone warning sign, either due to a lane shift or for the entire length of the work zone.



Source: Battelle

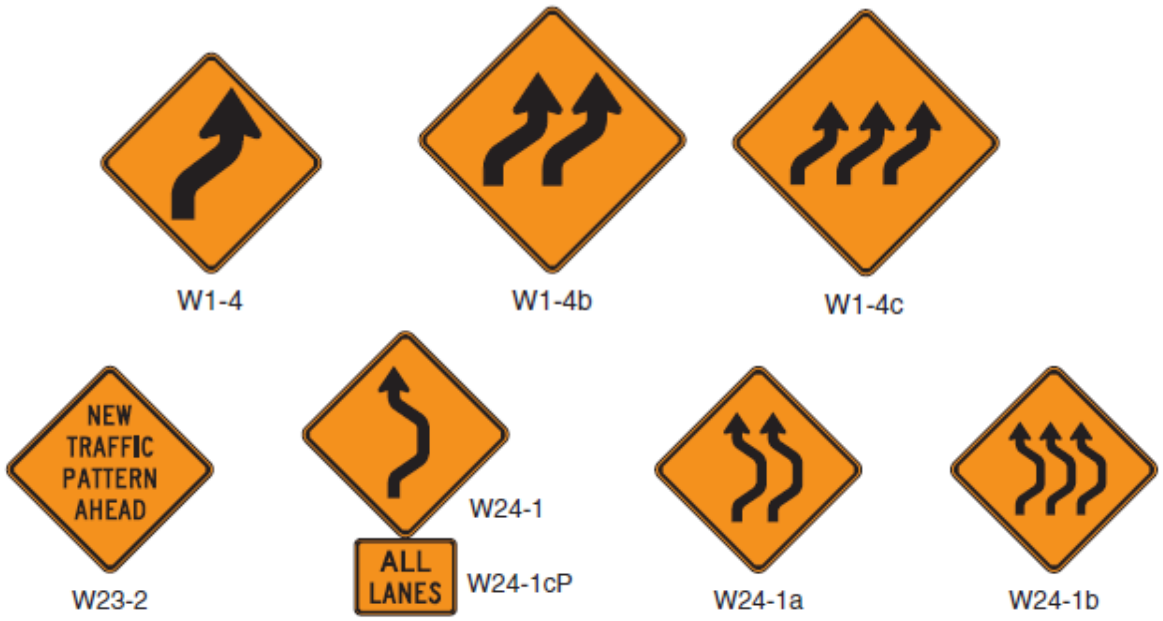
Figure A-6. MUTCD Signage for Reduced Speeds due to a Work Zone

If an advisory message is desired to inform drivers of the presence of a work zone, a number of options are given in the MUTCD, as shown in Figure A-7.

Source: Battelle

Figure A-7. MUTCD Signage to Indicate the Presence of a Work Zone

The RSZW/LC application may also provide advisory, alert, and/or warning messages to indicate changes to roadway geometry that involve lane shifts or lane closures. Figure A-8 shows MUTCD recommended signage for lane shifts, while Figure A-9 shows signs for lane closures.



Source: Battelle

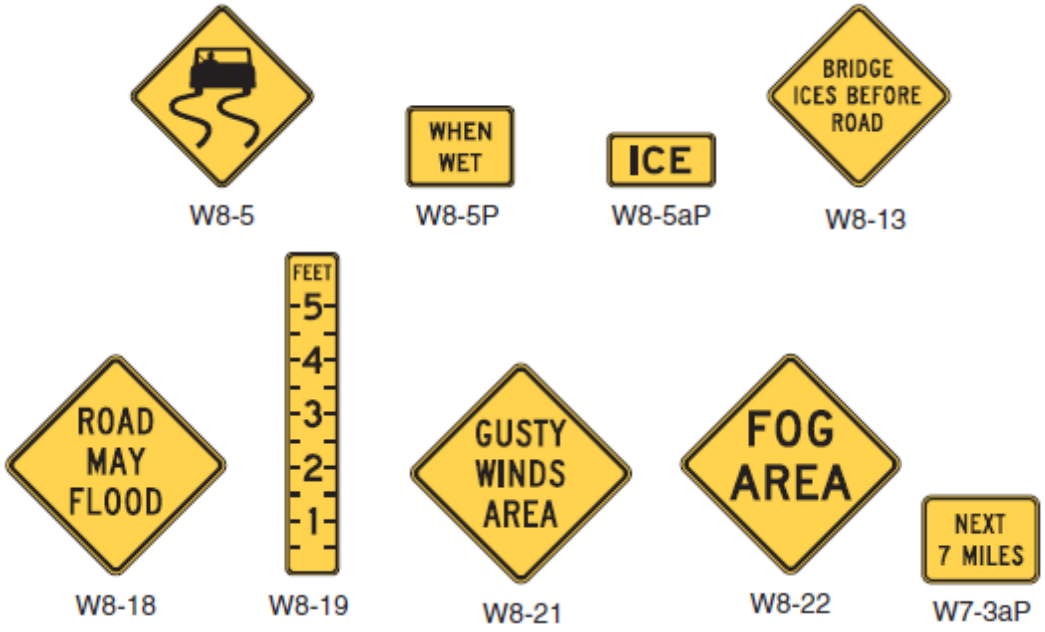
Figure A-8. MUTCD Signage to Indicate a Lane Shift due to a Work Zone

Source: Battelle

Figure A-9. MUTCD Signage to Indicate Lane Closures due to a Work Zone

A.7.4 SWIW-RS

The SWIW-RS application could be deployed for many different situations, including various weather events and their severity, as well as for various vehicle types. The MUTCD provides some recommended signage for various weather events, as shown in Figure A-10. Several of the signs presented there are intended to be used in conjunction with others (e.g., W8-5P or W8-5aP with W8-5, W8-19 only in addition to W8-18, and W7-3aP with W8-21 or W8-22). It is possible that the depth gauge sign could be adapted to a digital display to indicate water depth.



Source: Battelle

Figure A-10. MUTCD Signage used to Indicate Weather Conditions

While signage from Figure A-10 could be adapted for the SWIW-RS application to indicate the presence of an adverse weather-related condition, the signage in the following figures could be adapted to recommend or mandate an action by drivers. These recommended or mandated actions include an advisory speed (W13-1P) or enforceable speed limit (R2-1), shown in Figure A-11.

Source: Battelle

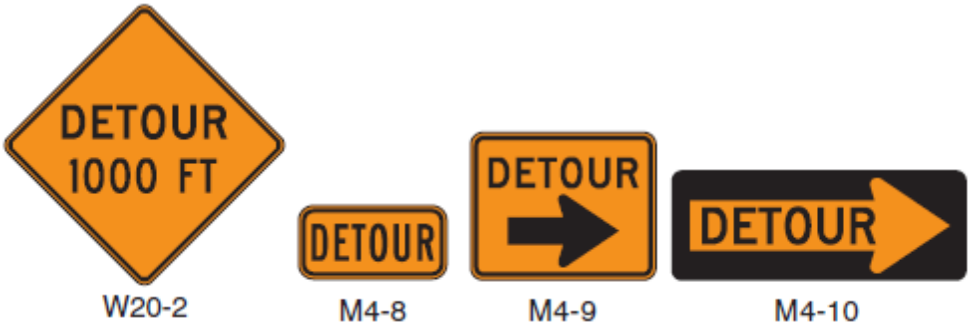
Figure A-11. Advisory Speed and Enforceable Speed Limit Signs from the MUTCD

A.7.5 SWIW-D

The SWIW-D application is intended to be deployed in the event of inclement weather conditions on a roadway ahead, such that diversion is either recommended or required for some or all vehicles, depending upon the severity and type of weather. The MUTCD includes guidance on signage to use in the event of a road closure, as shown in Figure A-12. An alternate route that is recommended in the event of a closure might include signage shown in Figure A-13.

Source: Battelle

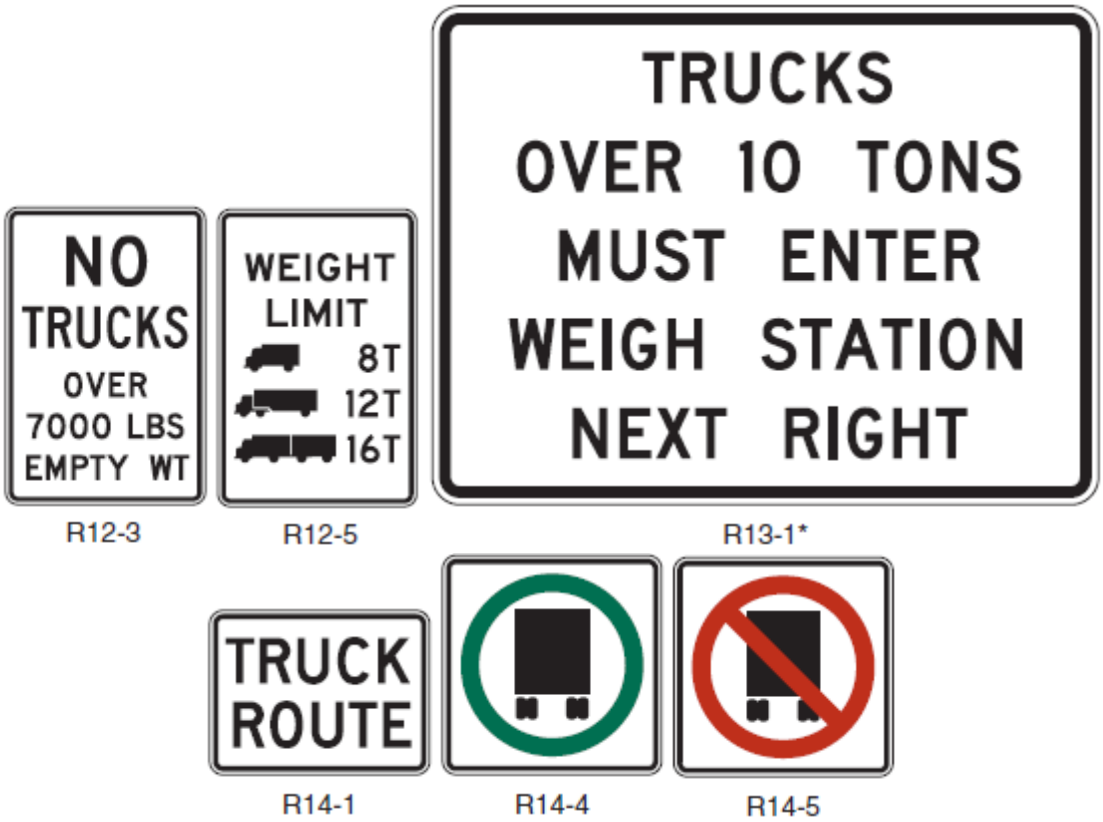
Figure A-12. MUTCD Signage used to Indicate Road Closures



Source: Battelle

Figure A-13. MUTCD Signs Employed to Direct Traffic on a Detour Route

The SWIW-D application may also issue advisory, alert, or warning messages that are specific to trucks, e.g., larger vehicles may be more severely impacted by high winds. In this case, signage from Figure A-10 to Figure A-13 may be combined with symbols or signage in Figure A-14 to indicate that a message is intended only for heavy vehicles.



*Note that the colors of R13-1 may be white-on-black or black-on-white

Source: Battelle

Figure A-14. MUTCD Signs used for Heavy Vehicles

A.7.6 SSGA

Unlike other V2I safety applications, the SSGA application does not have as many directly applicable signs in the MUTCD, and modifications are likely required for a deployment. Modifications might include a combination of the signs and symbols presented below in Figure A-15. Signage used at a deployment in Minnesota combines symbols from R6-3, R3-1, R3-2, and R3-27 to indicate the presence of vehicles approaching on a divided highway. For a two-lane road, a base sign such as W4-4P might be combined with directional arrows, over which appears symbols similar to R3-1, R3-2, and R3-27 to indicate the presence of cross-traffic.

Source: Battelle

Figure A-15. Select Signs from the MUTCD that could be Utilized in the SSGA Application

APPENDIX B. Equations and Resources for Determining Issuance of Alerts and Warnings

The V2I Safety Applications require numerous equations for calculating the timing and issuance of alerts and warnings. These equations are used differently for different applications, but are generally functions of the vehicle location, distance, speed, acceleration, and time. These variables are defined below, followed by an explanation of the equations themselves.

B.1 Key Variables for Determining Issuance of Alerts and Warnings

Acceleration, *a*, (or deceleration, when the value is negative) represents the change in vehicle speed. A default value of *a* is used by the infrastructure as the generic worst case vehicle deceleration rate that represents above average braking for the vehicle for these applications: CSW, RSZW/LC, SWIW-RS, and SWIW-D. A vehicle-specific value of *a* will be required by the vehicle for the vehicle-specific deceleration rate that represents above average braking for these applications: CSW, RLVW, SWIW-RS, and SWIW-D. Additionally, a second vehicle-specific value of is required by the vehicle for the vehicle-specific deceleration rate that represents aggressive braking for these applications: CSW, RLVW, and SWIW-D.

The value $d_f - d_i$ represents the distance along the roadway between the current position of the vehicle and crash-imminent hazard or zone it is approaching (an exception is for the SSGA application, for which this value is measured for the approaching remote vehicle on the intersecting roadway). For the purposes of these equations, this value is always positive. By application, the crash-imminent hazard or zone refers to:

- CSW: the beginning of the curve segment;
- RLVW: the intersection stop bar;
- RSZW/LC: the beginning of the reduced speed zone and, where applicable, the beginning of the changed roadway configuration;
- SWIW-RS: the beginning of the weather zone;
- SWIW-D: the point of the weather-induced road closure;
- SSGA: the intersection edge of the minor road with the major road that the remote vehicle is traveling on.

The value $v_f - v_i$ represents the change in speed required of the vehicle between its current position the crash-imminent hazard or zone it is approaching. This value is always negative or zero for the purposes of these applications. The value for v_i is the current speed of the vehicle. The value used for v_f is zero for the RLVW and SWIW-D applications and equal to the posted, advisory, and/or vehicle-specific safe speeds for the CSW, RSZW/LC, and SWIW-RS applications.

The value $t_f - t_i$ represents the time that will elapse from the current vehicle position until it reaches the crash-imminent hazard or zone it is approaching. This value is always positive or zero for the purposes of these applications. The value for t_i is always equal to zero, while the value used for t_f is an unknown variable that will be calculated. Although this variable could be used for the determination

of the issuance of alerts and warnings as time until reaching the crash-imminent hazard or zone, for the purposes of the V2I safety applications the value $d_f - d_i$ is used as the primary determining factor.

Equations for Determining Issuance of Alerts and Warnings

The equation used for the determination of the issuance of alerts and warnings for several applications is:

$$d_f - d_i = \frac{v_f^2 - v_i^2}{2a}$$

The variables in this equation change as the vehicle changes position and for each infrastructure and vehicle alert and warning that is calculated for an application. The variable *a* is known or assumed by the application for various road and weather conditions, and v_f is known for the application type and location. Specifically, the value of *a* used for determining DII alerts is stored by the infrastructure application and the values of *a* used for determining DVI alerts and warnings are vehicle-specific and stored by the vehicle. The value of v_f varies by application, and will typically be stored by the infrastructure, except for the determination of vehicle specific safe speeds for CSW and SWIW-RS. An alert or warning is issued when the calculated value of $d_f - d_i$ exceeds or is equal to the actual value of $d_f - d_i$ for the subject vehicle for the respective alert or warning *a*. Specifically, this equation is applied for the issuance of alerts and warnings for instances listed below in the following applications:

- CSW: DII Alert for a generic worst-case vehicle approaching a curve at an unsafe speed for known or assumed road and weather conditions, DVI Alert for a specific vehicle given vehicle-specific information, and DVI Warning for a specific vehicle given no response to previously-issued alerts;
- RLVW: DVI Alert and DVI Warning that are vehicle-specific and issued to a vehicle that needs to brake more to stop for an upcoming red light;
- RSZW/LC: DII Alert for a generic vehicle approaching a reduced speed zone to slow down;
- SWIW-RS: DII Alert for a generic vehicle approaching a weather zone to reduce speed given current road and weather conditions, and DVI Alert that provides a vehicle-specific message to a vehicle for slowing down given the current road and weather conditions and vehicle operating characteristics;
- SWIW-D: DII Alert for a generic vehicle approaching a weather-related road closure given current road and weather conditions; DVI Alert and Warning that are vehicle-specific and issued to a vehicle that needs to brake more to stop for an upcoming weather-related road closure.

The equation used for the issuance of alerts and warnings for the SSGA application is:

$$d_f - d_i = v_i(t_f - t_i) + \frac{1}{2}a(t_f - t_i)^2$$

The variables in this equation apply to remote vehicles approaching the minor road stop-controlled intersection from either direction. These variables change as the approaching remote vehicle changes position and for the specific infrastructure and vehicle alert and warning that is calculated for the application. The variable t_i is known to be zero, while v_i is derived from remote vehicle detection data provided by the infrastructure data systems. The variable *a* is assumed to be zero for the purposes of this application, given the frequency that the information for *v* and *d* are updated and the equation recalculated. The values for t_f represent the approaching remote vehicles' time to arrival at the minor road intersection edge, and will vary for each alert and warning based on gap rejection

behavior at that intersection. Specifically, the value of t_f used for determining DII alerts is stored by the infrastructure application and the values of t_f used for determining DVI alerts and warnings are vehicle-specific and stored by the vehicle. In the SSGA application, an alert or warning is issued when the calculated value of $d_f - d_i$ exceeds or is equal to the actual value of $d_f - d_i$ derived from the remote vehicle detection data that is collected by infrastructure data systems for the respective alert or warning t_f.

Other alerts and warnings are issued based on guidance in the Manual of Uniform Traffic Control Devices (MUTCD). The MUTCD guidance is based on similar calculations and engineering judgment regarding appropriate distances to inform drivers of a particular circumstance, such as the need to stop ahead. The MUTCD uses this value in conjunction with expected values for sign visibility distance and perception-response time (PRT) for a generic vehicle determining the distances at which the driver should receive a message along the roadway. This guidance is adapted in some instances to determine the distance at which to issue DII and DVI messages. For instance, any DII message issued by the vehicle is received by the driver when the distance between the vehicle and the DII message sign is equal to the sign visibility distance. The following applications employ MUTCD guidance for the issuance of these advisory, alert, and/or warning messages:

- CSW: a DII Advisory of the curve ahead based on MUTCD Table 2C-4;
- RLVW: a DII Advisory of the signalized intersection ahead based on MUTCD Table 2C-4;
- RSZW/LC: a DII Advisory of the reduced speed zone ahead based on MUTCD Table 2C-4, a DII advisory if a changed roadway configuration is present based on MUTCD Table 6C-1, and a DVI alert and warning given additional lane-level positioning information when a change in roadway configuration is present based on MUTCD Table 6C-1;
- SWIW-RS: a DII Advisory of the weather-related reduced speed zone ahead based on MUTCD Table 2C-4;
- SWIW-D: a DII Diversion Advisory suggesting or requiring diversion due to inclement weather ahead based on MUTCD Table 2C-4;
- SSGA: a DII Stop Ahead Advisory of the stop-controlled intersection ahead based on Table 2C-4.

Modifying Variables for Changing Circumstances

Various factors could impact specific variables used in calculating the above equations. For example, changing weather or road conditions and vehicle-specific operating characteristics can change the values used for the above equations. Lower friction due to road surface conditions or vehicle tire wear could increase the safe distances and safe deceleration rates. The vehicle type and operating characteristics could also impact when vehicle-specific alerts and warnings that are issued. Some of these variables are discussed below.

Side Friction Factor and Lateral Acceleration for CSW. The AASHTO "Policy on Geometric Design of Highway and Streets" [4] and local state DOT policies have parameters for design speeds that consider factors like functional classification, urban vs. rural conditions, terrain, legal speed limit, anticipated volume, development costs, and design considerations. Additionally, the maximum safe speed threshold for traversing a curve could be vary by vehicle type, road conditions, and weather conditions. AASHTO provides further guidance for considering these factors, specifically for

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

determination of the appropriate side friction factor, which can be used to derive a safe speed with this equation:

$$f = \frac{v^2}{15R} - 0.01e$$

In this equation, *R* is the radius of the curve, *e* represents the rate of roadway superelevation, and *f* is the side friction factor of the pavement and tires. The *f* value used should be substantially less than the coefficient of friction at impending skid. The side friction factor at impending skid depends 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. 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)

The side friction factor relates to lateral acceleration and varies by vehicle type in regards to rollover stability and tire adhesion. NCHRP 600 provides suggested maximum values for lateral acceleration and braking efficiency for dry conditions, where *g* is the acceleration due to gravity:

- Lateral Acceleration
  - SUVs and Buses: (0.7 *g*)
  - Passenger Cars: (0.8 *g*)
  - Laden Heavy Trucks: (0.35 *g*)
- Braking Efficiency
  - Passenger Cars: (0.9–1.0)
  - Heavy Vehicles: (0.5–0.6)

Perception Response Time. Perception-response time or perception-reaction time (PRT) is generally accepted to be 2.5 seconds by the MUTCD and AASHTO.[5] This time must be considered to account for the time and distance that the vehicle travels at the initial speed from the time the driver receives the message before reacting to it, and added to the value of time or distance needed for a car to decelerate to a stop or reduced speed. The MUTCD uses the value of 2.5 seconds for the placement of signage for a generic vehicle, which is used for determining the distances at which some DII and

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

DVI messages should be sent and received by the driver along the roadway. AASHTO supports this with evidence that this value encompasses the capability of most drivers, including older drivers. However, MUTCD guidance does not account for the issuance of messages that are planned for the V2I Safety Applications. For these circumstances, a modified PRT may be merited. The AASHTO "Policy on Geometric Design of Highways and Streets" does suggest that 2.5 seconds may not be adequate for the most complex conditions encountered in driving

Acceleration. The selected acceleration rates used for calculating alert and warning distances, specifically for decelerating to a reduced speed or a complete stop, could vary based on many factors. Some of these factors may not be required by the application and use default or assumed values if unavailable, such as the road surface friction or weather information. Other factors are static for each given deployment, such as the grade of the roadway. Still other factors vary at each deployment for each individual vehicle, such as the vehicle operating characteristics like the braking capabilities. The AASHTO "Policy on Geometric Design of Highways and Streets" indicates that most drivers decelerate at a rate that is greater than 14.8 ft/s^2 (4.5 m/s^2) when there is a sudden need to stop for an unexpected object in the roadway, while 90 percent of drivers decelerate at a rate over 11.2 ft/s^2 (3.4 m/s^2). These deceleration rates account for the comfort level of drivers, the ability of the driver to maintain steering control on wet surfaces in tandem with tire-pavement friction levels, and vehicle braking systems capabilities. As noted in this guidance, however, dry pavement systems and most vehicle braking systems can provide adequate braking friction that exceeds these rates when necessary. Thus, acceleration rates used for calculating alert and warning distances may require adjustment for these variables.

Acceptable Gap. The AASHTO "Policy on Geometric Design of Highways and Streets" and NCHRP 600 both discuss values for time gap for vehicles on a minor road waiting at a stop-controlled intersection. Specifically, NCHRP 600 provides values of time gap (t_g) for vehicles as shown in Table B-1 below for any major road design speed. AASHTO notes that studies have shown accepted time gaps to be constant for different design speeds on the major road.

Table B-1. Acceptable Time Gaps for any Major Road Design Speed

	Time Gap (seconds)	
Design Vehicle	**Left Turn**	**Right Turn**
Passenger Car	7.5	6.5
Single Unit Truck	9.5	8.5
Combination Truck	11.5	10.5

Source: NCHRP 600

Note that these values need to be adjusted for major roads that are multilane highways and for minor roads that have approach grades greater than 3 percent. Specifically, the time that must be added to these time gaps for these conditions are:

- Multilane Highways with more than two lanes, including narrow medians that cannot store the design vehicle
  - Passenger Cars: additional 0.5 seconds for each additional lane including narrow median
  - Trucks: additional 0.7 seconds for each additional lane including narrow median
- Approach Grades greater than 3 percent
  - Left Turn: 0.2 seconds for each percent grade
  - Right Turn: 0.1 seconds for each percent grade

NCHRP 600 also notes that there are many factors that could affect the acceptable gap, which could likewise impact the vehicle-specific gap distances that are used as a basis for issuing alert and warning messages for the SSGA application. These factors include driver age, wait times, and direction of turn.

APPENDIX C. Acronyms and Abbreviations

AADT	Annual Average Daily Traffic
AAHSTO	American Associated of State Highway and Transportation Officials
CAN	Controller Area Network
CMS	Changeable Message Signs
ConOps	Concept of Operations
CSW	Curve Speed Warning
DII	Driver-Infrastructure Interface
DMS	Dynamic Message Signs
DoCAN	Diagnostic Communication Over Controller Area Network
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
ESS	Environmental Sensor Station
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GNSS	Global Navigation Satellite Systems
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LOS	Levels of Service
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol
OEMs	Original Equipment Manufacturers
PRT	Perception Reaction Time
RLVW	Red Light Violation Warning
ROR	Run-Off-Road
RSZW	Reduced Speed Zone Warning
RSZW/LC	Reduced Speed Zone Warning with Lane Closure

RTCM	Radio Technical Commission for Maritime Services
RWIS	Road Weather Information Systems
SAE	Society of Automotive Engineers
SCP	Signal Control and Prioritization
SOI	System-of-Interest
SSGA	Stop Sign Gap Assist
SWIW	Spot Weather Information Warning
SWIW-D	Spot Weather Information Warning – Diversion
SWIW-RS	Spot Weather Information Warning – Reduced Speed
TBD	To Be Determined
TMDD	Traffic Management Data Dictionary
TRB	Transportation Research Board
TSS	Transportation Sensor Systems
U.S. DOT	United States Department of Transportation
UTC	Universal Time, Coordinated
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

APPENDIX D. Terms and Definitions

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

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

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

Degraded – Mode of the safety application where it is capable of providing a subset of its intended function(s).

Failure – Mode of the safety application where the safety application is incapable of providing any of its intended function(s).

False Alarm – Situation where the safety application provides an alert/warning to the driver when the conditions to not warrant an alert/warning.

Functional Class of Roadway – The functional class of roadways are defined in FHWA "Functional Classification Guidelines". Revised 1989.

Missed Alarm – Situation where the safety application does not provide an alert/warning to a driver when the conditions warrant an alert/warning.

Non-volatile Storage – Type of storage that remains intact even when there is no power.

Offline – State of the safety application where the safety application is not processing data or providing advisories, alerts and/or warnings.

Online – State of the safety application where the safety application is functioning and providing advisories, alerts and/or warnings.

Operational – Mode of the safety application where the safety application is capable of providing all of its intended function(s).

Perform – To work in a manner to achieve the desired outcome.

Physical Security – Describes measures that are designed to deny access to unauthorized personnel (including attackers or even accidental intruders) from physically accessing a building, facility, resource, or stored information; and guidance on how to design structures to resist potentially hostile acts.[6] 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".

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

Roadside Configuration Data – Data provided from the infrastructure data equipment or back office that details the lane(s), roadway geometry, and/or map of the area needed by a safety application

Road Weather Information – Data on road and weather conditions that may impact vehicle safety including visibility, wind speed, precipitation, air and road surface temperature, road surface condition, etc.

Roadway Work Zone Configuration Information – Data on work zone configuration elements that may impact vehicle safety including lane shifts, lane reductions, etc.

Roadway Work Zone Operations Information – Data on work zone operational elements that may impact vehicle safety including buffer zones, traffic control setup, temporary pavement markings, temporary traffic barriers, road closures, changed lighting conditions (during night work),etc.

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.

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.[7]

Vehicle Telematics Data – Data made available from vehicle electronic systems that could be utilized by the connected vehicle in-vehicle application. Examples include vehicle operating speed; operational status of windshield wipers, headlights, etc.; driver application of brakes or accelerator; etc.

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

[7] Traffic Monitoring Guide, U.S. DOT, May 2001, http://www.fhwa.dot.gov/ohim/tmguide/tmg4.htm#app4c

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487
www.its.dot.gov

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