

Federal Highway Administration (FHWA)
Vehicle-to-Infrastructure (V2I) Deployment
Guidance and Products

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16. Abstract This guidance is intended to assist Federal Highway Administration (FHWA) staff and transportation system owners/operators deploy V2I technology, not only in terms of the Federal-aid Highway program requirements, but also practices to help ensure interoperability and efficient and effective planning, procurement, and operations throughout the full lifecycle. V2I technology will take advantage of and build upon emerging vehicle-based technologies being deployed to support vehicle-to-vehicle (V2V) communications. When leveraged with V2V communications, a V2I deployment will result in significant safety, mobility, and environmental benefits that will be of significant interest to state, regional, and local transportation agencies. FHWA encourages deployments, but public agencies are not required to implement V2I technology or applications. Deployment of V2I technologies is not mandated by or coupled with the National Highway Traffic Safety Administration (NHTSA) rulemaking for vehicle-to-vehicle (V2V) communications. To achieve the maximum benefit, the V2I Deployment guidance and products document requires a thorough read of this material and the full use of the associated products. These products are separate reference documents and/or online software applications with a specific focus on V2I deployments.			
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FEDERAL HIGHWAY ADMINISTRATION VEHICLE-TO-INFRASTRUCTURE VISION AND POLICY STATEMENT

V2I VISION STATEMENT

The Federal Highway Administration (FHWA) will provide national leadership and facilitate a smooth and effective deployment path for transportation owners/operators who are interested in implementing vehicle-to-infrastructure (V2I) technology within a connected vehicle environment (CVE).

V2I POLICY STATEMENT

V2I technology will take advantage of and build upon emerging vehicle-based technologies being deployed to support vehicle-to-vehicle (V2V) applications. When leveraged with V2V communications, a V2I deployment will result in significant safety, mobility, and environmental benefits that will be of significant interest to State, regional, and local transportation agencies (1) (2). FHWA encourages deployments, but public agencies are not required to implement V2I technology or applications.

This document provides guidance and products to assist State, regional, and local agencies in the deployment of efficient and interoperable systems. FHWA has developed and will continue to develop materials to support V2I deployments that will ensure national interoperable and deployment success in accordance with applicable regulations.

CHAPTER 1. INTRODUCTION

To achieve the maximum benefit, the *Vehicle-to-Infrastructure Deployment Guidance and Products* requires a thorough read of this material (i.e., the “guidance”) and the full use of the associated products (i.e., the “products” in V2I Products). In addition, this document has numerous references to sources of information (see References), including relevant research articles, guidance materials, codification of general and permanent rules or laws, and pertinent websites. Some of the websites contain invaluable products that should be bookmarked or saved for future reference. The references are supplemental information that will broaden the reader’s knowledge. At the same time, they ensure this document remains concise without providing an exhaustive discussion on a given topic. Use of the guidance, products, and references can facilitate a smooth and effective V2I deployment.

1.1. INTENT OF THIS DOCUMENT

This guidance is intended to assist FHWA staff and transportation system owners/operators with deployment of V2I technology, not only in terms of the Federal-aid highway program requirements, but also practices to help ensure interoperability and efficient and effective planning, procurement, and operations throughout the full lifecycle of a deployment. Deployment of V2I technologies is not mandated by or coupled with the National Highway Traffic Safety Administration (NHTSA) rulemaking for vehicle-to-vehicle (V2V) communications (3). However, it is important for the State and local agencies to understand:

- What a decision to deploy V2I technology could mean to their region
- How to prepare for emerging V2I and V2V technology
- How Federal-aid funds could be leveraged to deploy V2I technology

The guidance, associated material, references, and products are useful resources to help those considering V2I deployments and/or to leverage V2V communications. Finally, this document is not intended to replicate information that is available in the NHTSA Federal Motor Vehicle Safety Standards – V2V Communication rulemaking. Please refer the rulemaking for more technical details such as performance criteria, privacy, security, credential management, estimated costs and benefits. Also, in the event that there are inconsistencies between this guidance and existing laws and regulations, the existing laws and regulations take precedence.

1.2. DOCUMENT ORGANIZATION

Five sections, summarized below, comprise the guidance, products, and references:

- 1) Introduction

- 2) Federal-Aid Eligibility for V2I Deployments
- 3) Guidance
- 4) V2I Products
- 5) Appendices

1.2.1. Introduction

The introduction has a three-fold objective:

- 1) Define the intent of this document
- 2) Define the terms “connected vehicle” and “vehicle-to-infrastructure” as they pertain to the guidance
- 3) Address the significance of V2I technology to FHWA staff, transportation system owners/operators, and individuals interested in deploying V2I technology

1.2.2. Federal-aid Eligibility for V2I Deployments

The Federal-aid eligibility section has two subtopics that establish general eligibility for V2I activities and a brief summary of various eligibility requirements. In short, this section seeks to promote and encourage use of Federal-aid programs for V2I deployments that meet the eligibility requirements. This section is crucial for those responsible for making V2I funding decisions.

1.2.3. Guidance

The guidance section has 23 subtopics focusing on reducing the learning curve, increasing reliability, and maintaining the quality of V2I deployment designs, deliverables, or services. This section elaborates on the methods or techniques that have consistently shown superior results over the full lifecycle of a project. The section provides the most recent initiatives in connected vehicle applications based on a collection of research articles. A few subtopics relate to Federal, State, and local regulations, so the items should be addressed on a case-by-case basis during the planning or design phase of a project.

1.2.4. V2I Products

The products section includes eight V2I deployment resources, currently under development, to facilitate an effective deployment:

- 1) System engineering process for V2I
- 2) Incorporation of connected vehicles into the transportation planning process
- 3) Desk reference and tools for estimating the local, regional, and statewide economic development benefits of connected V2I deployments
- 4) Guide to licensing dedicated short-range communication (DSRC) roadside units (RSUs)
- 5) V2I message lexicon

- 6) Near-term (0- to 5-year) V2I transition and phasing analysis
- 7) V2I pre-deployment guidance
- 8) White paper on U.S. Department of Transportation (USDOT) connected vehicle training resources

These products are separate resource materials that will be available in the 2016/2017 timeframe with a specific focus on V2I deployments. Since the products are still under development, this section describes the products, provides a hyperlink to the product, and provides a projected date of availability for each product.

1.2.5. Appendices

The appendices include references, definitions, symbols, and abbreviations. The USDOT published the majority of the references in connection with V2I and V2V research; hyperlinks are available for quick download. The full text of the eligibility guidance is available with hyperlinks. The definitions, symbols, and abbreviations are common terms used in V2I and V2V communication.

1.3. DEFINITION OF A CONNECTED VEHICLE AND V2I COMMUNICATION

The USDOT has not adopted an official definition of a “connected vehicle,” and the term has evolved to include various modes of telecommunications, numerous automation levels, and differing information processes. In this guidance document, the term connected vehicle is defined as “combining leading edge technologies—advanced wireless communications, onboard computer processing, advanced vehicle-sensors, Global Positioning System (GPS) navigation, smart infrastructure, and others—to provide the capability for vehicles to identify threats, hazards, and delays on the roadway and to communicate information over wireless networks to provide drivers with alerts, warnings, and real-time road network information.” Although there are several components of connected vehicle technology, this document focuses on V2I communication and applications (4).

In a similar manner, this document uses a broader context of V2I communication to mean both vehicle-to-infrastructure communication and infrastructure-to-vehicle (I2V) communication. Normally, one-way communication is distinguished by labeling the initiator of the communications first—vehicle communication from a vehicle to the infrastructure’s receiver is called V2I, while infrastructure communication sent to the vehicle’s receiver is called I2V. Hence, the two-way communications between vehicles and infrastructure will be designated as V2I in this guidance document.

1.4. SIGNIFICANCE OF V2I

To reduce costs, State, regional, and local transportation agencies are likely to leverage existing intelligent transportation systems (ITS) equipment in V2I deployments (e.g., dynamic message signs, closed-circuit television cameras, vehicle detection stations, and existing traffic signal controllers). Normally, ITS deployments are located in strategic areas because these locations provide an opportunity to utilize existing power sources, cabinet space, and backhaul communications for V2I equipment to minimize deployment costs.

Conceptually, a V2I deployment is similar to installing ITS equipment; there may be a need for siting, foundation, mounting points, electrical requirements, physical access, security, and a backhaul network. V2I deployments may also require additional tasks (e.g., evaluation of surrounding roadway geometry necessary for proper antennae placement to ensure adequate line-of-sight distance of 300 meters on all intersection approaches for optimal performance). In many cases, V2I deployments will need to be integrated with existing ITS equipment to enable direct data communications between the infrastructure and vehicles.

New and emerging technologies offer an opportunity to significantly enhance safety through communications among vehicles, infrastructure, and mobile devices, and there is also potential to leverage this technology to improve mobility and further enhance safety through interaction with the road infrastructure (1) (2). Although in many respects V2I technology resembles traditional ITS deployments, subtle differences must be considered:

- The technology will benefit from a level of national interoperability and functionality not found in today's ITS deployments;
- Because of its cooperative and networked approach, the technology requires starting any design and implementation with careful attention to security and privacy;
- The basic technologies that form connected vehicle systems are evolving at a dynamic pace.

1.5. AVAILABLE CONNECTED VEHICLE STANDARDS

By definition, a standard is a rule or principle used as a basis for judgment or for a level of quality. In the context of V2V/V2I, there are two types of standards to consider: (a) the Federal Motor Vehicle Safety Standards (FMVSS) mandated by NHTSA or similar regulatory requirements issued by other government bodies, such as the Federal Communications Commission (FCC); and (b) voluntary consensus standards developed by non-governmental standards organizations such as Society of Automotive Engineers International (SAE) and Institute of Electrical and Electronic Engineers (IEEE). In this document, the term connected vehicle standards will refer to the latter type of voluntary standards. Likewise, connected vehicle standards include rules that provide the software programming codes, definitions, and formats needed to create interoperable, consistent, and seamless communications exchange among shared information systems and devices (5).

The USDOT's ITS Standards Program facilitates the development of voluntary consensus standards and protocols that establish rules for how ITS, connected vehicle devices, vehicles, and operations centers can exchange information with one another. The vision for the ITS Standards Program is to facilitate interoperability between connected vehicle and ITS services within a complex, multimodal, connected transportation network. The USDOT provides the current status of the ITS Standards Program, fact sheets, testing, deployment contacts, training, and an interactive ITS Standards Forum within a centralized website at <http://www.standards.its.dot.gov/>.

In addition, the USDOT has created a Connected Vehicle Reference Implementation Architecture (CVRIA) that spans all ITS standards activities and provides a means of detecting gaps, overlaps, and inconsistencies between the standards (6). The CVRIA is an initiative that defines the architecture views for connected vehicle technologies and identifies their key interfaces to analyze where standards may be optimized for interoperability or beneficial for operations. The CVRIA has four viewpoints—Enterprise View, Functional View, Physical View, and Communication View.

The FHWA has undertaken a standards development plan to continuously identify and prioritize candidate standards needed in support of connected vehicle implementation. The plan considers adoption of existing industry standards from other areas, adaptation of existing standards, or development of new standards if existing standards are not viable. When a connected vehicle architecture view is mature, the standard is incorporated into the National ITS Architecture.

1.6. DEFINITION OF A CONNECTED VEHICLE ENVIRONMENT

In any connected vehicle deployment that involves a mixture of vehicle-based and infrastructure-based components, there will be a number of common elements. Mobile devices, for instance, may include onboard equipment (OBE) on any number of vehicle classes, as well as personal portable mobile devices—the most prevalent example of which is a smart phone.

Each of these devices can provide information about its situation to other equipped devices such as other vehicles, called remote vehicle OBEs, and systems that make up the infrastructure. Roadside equipment (RSE) that includes V2V devices can receive information from the equipped vehicles, via V2I communication, as they pass within range. The RSEs can, in turn, provide this data through a data distribution system (DDS) that acts as a clearinghouse to provide the situational data to centers (e.g., traffic management or transportation information centers).

All of these devices, their communications, and the interactions among them constitute a connected vehicle environment (CVE).

1.7. FUTURE UPDATES TO THIS DOCUMENT

As deployments come online and the technology matures, this guidance will be assessed for relevancy, compatibility with real-world deployment issues, and newly enacted transportation and communication statutes and regulations. When needed, this guidance will be updated and modified.

As more V2I deployments occur, FHWA will have enough information and data to conduct a full benefit-cost analysis of V2I services to measure the safety, mobility, and environmental benefits to State, regional, and local transportation agencies. Based on this analysis, the deployment of these services will be encouraged by FHWA, but will be voluntary. FHWA will develop more materials needed to support deployment (e.g., guides, tools, and best practices) with a long-term goal of ensuring that V2I services are geographically interoperable and developed in accordance with the requirements in Part 940 of Title 23 within the Code of Federal Regulations (23 CFR 940) and other applicable regulations.

Although this guidance does not address automated or autonomous vehicles, this technology is not precluded by the FHWA V2I deployment guidance and may, in fact, be addressed by the guidance in the future.

1.8. EXISTING LAWS AND REGULATIONS

This guidance was developed through cross-modal cooperation at the Federal, State, and local levels. The guidance is intended to assist transportation agencies in making appropriate investment and implementation decisions when deploying V2I systems. It does not negate or replace existing processes, but rather aims to provide a clear statement of FHWA policy regarding such processes as planning, funding, siting, procuring, using, and providing access, among other critical actions. In the event that there are inconsistencies between this guidance and existing laws and regulations, the existing laws and regulations take precedence.

Please refer to the NHTSA V2V rulemaking for essential regulations and technical details such as performance criteria, privacy, security, and credential management

CHAPTER 2. FEDERAL-AID ELIGIBILITY FOR V2I DEPLOYMENTS

V2I deployments are essentially upgraded ITS deployments with a focus on specific V2I applications (e.g., safety, mobility, and environment). Most V2I deployments will qualify for similar Federal-aid programs as ITS deployments if they meet the eligibility requirements in the applicable statutes and regulations. There is ample Federal-aid eligibility for V2I investments that improve safety, mobility, congestion, and/or air quality.

2.1. GENERAL ELIGIBILITY FOR V2I ACTIVITIES

Equipment, installation, preventive maintenance, and operational costs that support V2I applications and are compatible with the basic connected vehicle standards for interoperability and security standards are eligible for Federal-aid funding where eligibility for ITS investments has been previously established. In regards to operational costs, FHWA has issued a Federal-aid eligibility policy guide on the operating costs for traffic monitoring, management, and control systems, such as integrated traffic control systems, incident management programs, and traffic control centers. The FHWA policy guide provides several examples of capital improvement, installation and integration, and traffic systems that may be eligible for Federal-aid funding (7).

Preventive maintenance associated with V2I systems is considered to be an operating cost and eligible for Federal-aid funding. Examples of these costs include activities to ensure peak performance (such as preventive computer maintenance); replacement of defective or damaged computer components; or other traffic management system hardware (including street-side hardware). Routine upkeep items that are not critical to maintaining continuous operation of the system (e.g., painting and grounds keeping) are not eligible for Federal-aid funding.

Marginal additional costs to purchase and install ITS equipment or communication technology capable of being upgraded or modified to operate in a deployed V2I environment at a future date are eligible for Federal-aid funding. In fact, it is recommended that as soon as V2I technologies are available, such equipment should be the standard for deployment.

Procurement of spare “system-critical” parts (i.e., essential for the successful operation of the system) that are susceptible to failure, regardless of reason, are eligible if identified in a deployment maintenance and replacement plan (see Reliability).

2.2. BRIEF SUMMARY OF FEDERAL-AID PROGRAMS FOR V2I ACTIVITIES

This section presents a short description of Federal-aid programs; the references provide a full description, eligibility requirements, and detailed guidance.

2.2.1. Highway Safety Improvement Program (HSIP)

V2I safety applications are eligible for HSIP funds if they address a State’s Strategic Highway Safety Plan (SHSP) priorities, are identified through a data-driven process, and contribute to a reduction in fatalities and serious injuries (8).

On October 1, 2012, FHWA issued an HSIP Moving Ahead for Progress in the 21st Century Act (MAP-21) Interim Eligibility Guidance (9). The HSIP is a Federal-aid program focusing on achieving a significant reduction in fatalities and serious injuries on all public roads. The Interim Eligibility Guidance provides a framework for the identification and analysis of highway safety problems, general roadway safety management practices, and a flow chart that shows the relationship between the SHSP and HSIP.

2.2.2. National Highway Performance Program (NHPP) and Surface Transportation Program (STP)

Costs that support V2I mobility and safety applications and that are compatible with the basic connected vehicle standards for interoperability and security may be eligible for NHPP and STP funds (10) (11). Per the statute, NHPP-funded projects shall be used for a facility located on the National Highway System (per 23 U.S.C. 119(c)) and should lead to advancement of the mobility, freight, condition, and safety goals established at 23 U.S.C. 150(b) (per 23 U.S.C. 119(e)(2)). Criteria for eligible projects are listed at 23 U.S.C. 119(d). Eligibility criteria for funding under the STP are set forth at 23 U.S.C. 133.

2.2.3. Congestion Mitigation and Air Quality (CMAQ) Improvement Program

Per 23 U.S.C 149, each CMAQ project must meet three basic criteria:

- 1) Be a transportation project
- 2) Generate an emissions reduction
- 3) Be located in or benefit a nonattainment or maintenance area

The CMAQ program provides a flexible funding source to State and local governments for transportation projects and programs to help meet the requirements of the Clean Air Act. All phases of eligible projects—not only construction—are eligible for CMAQ funding. This includes studies that are part of the project development pipeline (e.g., preliminary engineering) under the National Environmental Policy Act (NEPA). However, general studies that fall outside

project development do not qualify for CMAQ funding. Additional information is available in the *CMAQ Program Guidance* (12).

FHWA determines the eligibility of all projects, except those related to transit. The Federal Transit Administration (FTA) determines the eligibility of transit projects. While the eligibility determination is not made jointly, FHWA, FTA, and the Environmental Protection Agency field offices should establish and maintain a consultation and coordination process for timely review of CMAQ funding proposals, including those related to V2I.

ITS projects that support V2I applications, including equipment and installation costs, may be eligible for CMAQ funding provided they meet the project eligibility criteria under 23 U.S.C. 149(b). CMAQ funds may also be used for operational assistance subject to the limitations as described in the *CMAQ Program Guidance*. Examples of V2I projects and applications, such as SPaT, eco-drive, congested intersection adjustment, and traveler information systems, may be eligible for CMAQ funds as they can be effective in relieving traffic congestion, enhancing transit bus performance, and improving air quality.

Transit projects that support V2I applications may be eligible for CMAQ funds. For such projects, after FTA determines a project to be eligible, CMAQ funds will be transferred, or “flexed,” from FHWA to FTA, and the project will be administered according to the appropriate FTA program requirements. The *CMAQ Program Guidance* includes a section on CMAQ-eligible transit projects.

Although use for purely research deployments with test vehicles (e.g., the ITS Joint Program Office’s (JPO) Safety Pilot Model Deployment) would not meet the eligibility test, deployments may be eligible where (1) fully functioning equipped cars (either factory or aftermarket installations) will interact with the technology and impact mobility and (2) the research deployments may ultimately be incorporated in the wider deployment of the technology.

CHAPTER 3. GUIDANCE

The guidance in this chapter can be used to enhance the reliability, consistency, and quality of a V2I deployment design, deliverables, or services. The guidance and best practice methods can reduce the learning curve for new V2I deployments. Deviation from these methods should be made only after careful consideration of the necessary drivers and consequences. A number of connected vehicle or V2I applications are available for which these methods should be assessed to determine their applicability. These methods are the general outline for a variety of situations; however, it is important to stay abreast of the industry as the guidance and best practices will continue to evolve with technology.

A few of the subtopics in this chapter involve mandatory legislated standards (or regulations), but they may or may not apply to all V2I deployments. Therefore, the standards or regulations should be addressed on a case-by-case basis by consulting with legal counsel. The order of best practice subtopics below does not reflect a greater or lower degree of importance.

3.1. CONNECTED VEHICLE APPLICATIONS

Deployment of V2V and V2I hardware requires software to implement and realize the overall benefits of the CVE. In this document, the term connected vehicle applications will be used in a broader context to refer to “any program or group of programs that are designed to use V2V or V2I communications in conjunction with end user or connected vehicle technology.”

To determine the benefits of connected vehicles, a software application analysis was published in 2013 titled *National Connected Vehicle Field Infrastructure Footprint Analysis–Applications Analysis* (13). The document provided a summary of connected vehicle applications and their deployment needs by surveying several references from the perspective of connected vehicle system deployments including:

- The American Association of State Highway and Transportation Officials (AASHTO) Connected Vehicle Infrastructure Deployment Analysis (14)
- USDOT connected vehicle programs for safety, mobility, and environment across all modes
- State and local programs addressing agency planning, operations, and maintenance
- Special case for international land border crossings, combining some aspects of other USDOT and State programs

The survey focused on identifying: (1) operational needs that might be addressed by connected vehicle applications, (2) the aspects of deployment that are shared by the applications, and (3) how those common attributes might be leveraged to reduce costs and increase deployment benefits. The applications were assembled into application *groups* and *bundles* within each group. The application *groups* were categorized by objective and concerns such as V2I Safety, V2V Safety, Agency Data,

Environment, Road Weather, Mobility, and Smart Roadside. The application *bundles* were categorized within *groups* by function, mode, or a combination of attributes.

Table 1 provides a list of the connected vehicle applications categorized by *groups* and *bundles*. The USDOT website provides a brief description of each application along with supporting research documentation. Additional connected vehicle applications are being developed in partnership with other USDOT modes (e.g., the FTA, Federal Railroad Administration, and Federal Motor Carrier Safety Administration); brief descriptions can also be found at the USDOT website along with supporting research documentation (15).

Table 1: Connected Vehicle Applications

V2I Safety	Environment	Mobility
<ul style="list-style-type: none"> Red Light Violation Warning Curve Speed Warning Stop Sign Gap Assist Spot Weather Impact Warning Reduced Speed/Work Zone Warning Pedestrian in Signalized Crosswalk Warning (Transit) 	<ul style="list-style-type: none"> Eco-Approach and Departure at Signalized Intersections Eco-Traffic Signal Timing Eco-Traffic Signal Priority Connected Eco-Driving Wireless Inductive/Resonance Charging Eco-Lanes Management Eco-Speed Harmonization Eco-Cooperative Adaptive Cruise Control Eco-Traveler Information Eco-Ramp Metering Low Emissions Zone Management AFV Charging/Fueling Information Eco-Smart Parking Dynamic Eco-Routing (light vehicle, transit, freight) Eco-ICM Decision Support System 	<ul style="list-style-type: none"> Advanced Traveler Information System Intelligent Traffic Signal System (I-SIG) Signal Priority (transit, freight) Mobile Accessible Pedestrian Signal System (PED-SIG) Emergency Vehicle Preemption (PREEMPT) Dynamic Speed Harmonization (SPD-HARM) Queue Warning (Q-WARN) Cooperative Adaptive Cruise Control (CACC) Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG) Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE) Emergency Communications and Evacuation (EVAC) Connection Protection (T-CONNECT) Dynamic Transit Operations (T-DISP) Dynamic Ridesharing (D-RIDE) Freight-Specific Dynamic Travel Planning and Performance Drayage Optimization
V2V Safety		
<ul style="list-style-type: none"> Emergency Electronic Brake Lights (EEBL) Forward Collision Warning (FCW) Intersection Movement Assist (IMA) Left Turn Assist (LTA) Blind Spot/Lane Change Warning (BSW/LCW) Do Not Pass Warning (DNPW) Vehicle Turning Right in Front of Bus Warning (Transit) 		
Agency Data	Road Weather	Smart Roadside
<ul style="list-style-type: none"> Probe-Based Pavement Maintenance Probe-Enabled Traffic Monitoring Vehicle Classification-Based Traffic Studies Connected Vehicle-Enabled Turning Movement and Intersection Analysis Connected Vehicle-Enabled Origin-Destination Studies Work Zone Traveler Information 	<ul style="list-style-type: none"> Motorist Advisories and Warnings (MAW) Enhanced Maintenance Decision Support System (MDSS) Vehicle Data Translator (VDT) Weather Response Traffic Information (WxTINFO) 	<ul style="list-style-type: none"> Wireless Inspection Smart Truck Parking

There are eight V2I applications that complement the V2V safety applications because they address crash scenarios more efficiently with low levels of penetration of V2V-equipped light vehicles. The following are the V2I safety applications that were recommended in the NHTSA readiness report of V2V technology for application (16):

- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Reduced Speed Zone Warning
- Spot Weather Information Warning
- Stop Sign Violation Warning
- Railroad Crossing Violation Warning
- Oversize Vehicle Warning

Over time, the FHWA expects that the public and private sectors will develop additional applications to meet safety, mobility, and environmental objectives.

3.2. PLANNING FOR V2I ACTIVITIES

Connected vehicle applications, including V2I applications, have the potential to fundamentally advance surface transportation safety and operations. While interactions between vehicles and infrastructure have been mostly passive and detached across the network to date, connected vehicle applications will allow them to work together, both actively and cooperatively. While we do not yet know the full magnitude, this could provide opportunities for congestion reduction and safety improvements beyond V2V safety applications, as well as improved traveler services and information. To fully realize the potential of V2I communications, V2I site deployments, operations, data access, and exchanges (among other functions) will require even closer collaboration among transportation modes, public jurisdictions, and the private sector.

To this end, metropolitan planning organizations (MPOs), local public agencies, transit operators, and States should begin considering V2I strategies in their long-range planning. Discussion topics could include a general understanding of the system, which application options work well under what conditions, pros and cons of each option, capital costs and availability of funding, integration with the existing systems including traffic management and communication networks, long-term impacts, cooperation and coordination across MPO boundaries and across State boundaries, staff needs, and the integration of these options into the existing statewide or regional ITS architectures.

The National ITS Architecture provides a common framework to guide planning, defining, and integrating ITS at the State and regional levels (17). The National ITS Architecture is a mature product that reflects the contributions of a broad cross-section of the ITS community (transportation practitioners, systems engineers, system developers, technology specialists, consultants, etc.). The architecture defines:

- The functions (e.g., gather traffic information or request a route) that are required for ITS
- The physical entities or subsystems where these functions reside (e.g., the field or the vehicle)
- The information flows and data flows that connect these functions and physical subsystems together into an integrated system

To support planning for CVEs, the following work is ongoing:

- FHWA is developing a planning guide to support analysis of investment options. A companion deployment guide is also under development to provide technical considerations for costing, siting, and installing V2I technologies
- Application requirements are emerging and can be found on the CVRIA website: www.its.dot.gov/arch/index.htm

3.3. NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) AND NATIONAL HISTORIC PRESERVATION ACT (NHPA)

There are V2I deployments that will require hardware equipment with antennae installations. These deployments must follow certain Federal, State, and local laws and regulations. This equipment will range from RSUs, antennae, cabinets and enclosures, pole mounts, and supporting ancillary equipment. Therefore, the installation of hardware and ancillary equipment for V2I deployments must follow certain regulations and/or obtain the following approvals, if necessary (18):

- Approval from the State or local governing authority
- Compliance with the NEPA
- Compliance with the NHPA

NEPA and NHPA obligations extend to the Federal agencies for which the activity in question constitutes an “action” (for NEPA) or “undertaking” (for NHPA). Federal V2I deployments likely constitute actions and undertakings for the USDOT and also for the FCC, meaning that they must comply with both agencies implementing regulations.

With respect to USDOT’s requirements, V2I deployments are most likely covered under 23 CFR 771.117(c) (21) as a Categorical Exclusion (CE) for certain ITS (19). Since the deployments generally have the primary function to improve the efficiency or safety of a surface transportation system, support the connected vehicle security system, and enhance passenger convenience, they are likely covered by this section. Additionally, these deployments typically will be within the existing operational right of way, will conform to the criteria in section 23 CFR 771.117(a), and are not likely to trigger the unusual circumstance provisions discussed in 23 CFR 771.117(b).

With respect to FCC requirements, V2I equipment that only receives BSM data is exempt from certain FCC, NEPA, and NHPA requirements, but V2I equipment that transmits BSM data is not

exempt. If the V2I equipment only receives BSM data, V2I equipment will not, in general, consume radio frequency bandwidth or present interference with other transmitters. Each deployment should be evaluated against the FCC regulations as well as State and local regulations. In particular, each deployment must comply with the FCC's regulations for facility siting. Additional information on these requirements is available at <https://www.fcc.gov/encyclopedia/tower-and-antenna-siting>.

3.4. INTEROPERABILITY

To achieve the vision of this V2I deployment guidance, V2I deployments will need to be interoperable and coordinated with other modes of transportation (e.g., light- and heavy-duty vehicles, transit systems, and railroad crossings) to operate on a national level. To the maximum extent possible, all devices and applications deployed by jurisdictions and modes should leverage the standards outlined in this section and should not be standalone deployments.

To operate properly, V2I deployments should be compatible with connected vehicle security policies and technologies that may be developed, support the distribution and/or receipt and use of any security credentials, and protect privacy at the highest level appropriate to the CVE application.

An operable CVE relies on the exchange of information, predominantly a BSM emanating from vehicles, but other messages as well. Specifically, FHWA recommends that a BSM conform to the technical standards proposed in the NHTSA V2V rulemaking, and employ the appropriate security and message authentication approaches. Since vehicles and devices may interact with equipment from all over the nation, the requirements for transmission and receipt of BSMS, including security, should be standard across the nation and across vehicle makes and models; device makes and models; and applications when related to safety-critical messages. Similarly, V2I deployments should conform to these same requirements in order for successful exchange of information between vehicles, devices, and applications within the CVE.

Although deployment of V2I components is voluntary, to the greatest extent possible, the functionality and utility of deployed applications should be consistent between transportation modes and regions and for deployed V2I equipment and/or applications to be eligible for Federal-aid funding and should comply with existing ITS and connected vehicle guidance and processes provided by the USDOT. Upcoming reference manuals and reports will highlight where local choice is an option or where uniformity is required or offers a greater benefit.

Table 2 illustrates the types of messages and the message handler required to enable a variety of V2I applications (6). Note that the list of applications in Table 2 is illustrative and not exhaustive. It is anticipated that industry will create additional applications that serve driver needs and agency requirements.

Table 2. V2I Messages by Application and Message Handler

Application	Message Handler													
	Position Correction Message Handler	Map Message Handler		BSM/ Approaching Vehicle Aggregator	Traffic and Rail Signal Message Handler		Local Weather and Road Surface Message Handler (Map Overlay)	Roadside Signage DMS Arbitrator	Local/Back Office User Interface					
	Position Correction Message	Local Map Message	Traffic Signage Data	Approaching Vehicle Mess	BSM (V2I)	Vehicle Weather Data	Oversize Vehicle Detection	SPaT Messages (SRM, SSM)	Rail Crossing SPaT	Ped Crossing SPaT	Local Weather Message	Road Surface Condition Mess	Dynamic Roadside Sign Mess	Installation, Configuration, Maintenance
INFLO-Queue Warning (Q-WARN) (TME Based)	✓	✓		✓	✓	✓							✓	✓
INFLO-Speed Harmonization (SPD-HARM) (TME Based)		✓		✓	✓	✓							✓	✓
Intelligent Traffic Signal System (ISIG)	✓	✓			✓			✓						✓
Emergency Vehicle Priority	✓	✓			✓			✓						✓
Transit Signal Priority	✓	✓			✓			✓						✓
Freight Signal Priority	✓	✓			✓			✓						✓
Pedestrian Mobility		✓			✓			✓		✓				✓
Eco-Traffic Signal Timing	✓	✓			✓			✓						✓
Eco-Approach and Departure at Signalized Intersections	✓	✓			✓			✓						✓
Eco-Traffic Signal Priority	✓	✓			✓			✓						✓
Eco-Driving - Connected Eco-Driving	✓	✓			✓			✓						✓
Dynamic Low Emissions Zones	✓	✓			✓			✓						✓
Dynamic Eco-Lanes	✓	✓			✓			✓						✓
Enhanced Maintenance Decision Support System (MDSS)	✓	✓			✓	✓					✓	✓		✓
Information for Maintenance and Fleet Management Systems	✓	✓			✓	✓					✓	✓		✓
Weather-Responsive Traffic Management		✓	✓	✓	✓						✓	✓	✓	✓
Motorist Advisories and Warnings		✓	✓	✓	✓						✓	✓	✓	✓
Information for Freight Carriers	✓	✓			✓	✓					✓	✓		✓
Information and Routing Support for Emergency Responders	✓	✓			✓	✓					✓	✓		✓

Application	Message Handler													
	Position Correction Message Handler	Map Message Handler	BSM/ Approaching Vehicle Aggregator			Traffic and Rail Signal Message Handler	Local Weather and Road Surface Message Handler (Map Overlay)		Roadside Signage DMS Arbitrator	Local/Back Office User Interface				
	Position Correction Message	Local Map Message	Traffic Signage Data	Approaching Vehicle Mess	BSM (V2I)	Vehicle Weather Data	Oversize Vehicle Detection	SPaT Messages (SRM, SSM)	Rail Crossing SPaT	Ped Crossing SPaT	Local Weather Message	Road Surface Condition Mess	Dynamic Roadside Sign Mess	Installation, Configuration, Maintenance
Red-Light Violation Warning (RLVW)		✓	✓					✓			✓	✓		✓
Stop Sign Gap Assist (SSGA)		✓	✓	✓	✓								✓	✓
Curve Speed Warning (CSW)		✓	✓	✓	✓						✓	✓	✓	✓
Stop Sign Violation Warning (SSVW)		✓	✓								✓	✓		✓
Railroad Crossing Violation Warning (RCVW)		✓	✓					✓	✓		✓	✓		✓
Spot Weather Information Warning (SWIW)		✓	✓	✓	✓						✓	✓	✓	✓
Oversize Vehicle Warning (OVW)	✓	✓	✓	✓	✓		✓						✓	✓
Reduced Speed Zone Warning (RSZW)	✓	✓	✓	✓	✓						✓	✓	✓	✓

3.5. EVALUATION

Due to the newness of connected vehicle and V2I technology, it is important to determine the effectiveness in meeting an identified need, benefits and cost, and user satisfaction assessment of these early deployments and the value of the investment. Evaluations are critical to understanding not only the technology as a whole but the specific applications and how and when to deploy, and to assist in the planning process. There are general ITS project resources that will be useful for this purpose (e.g., the *ITS Evaluation Guidelines – ITS Evaluation Resource Guide* found at www.its.dot.gov/evaluation/eguide_resource.htm).

3.6. ITS EQUIPMENT CAPABILITY AND COMPATIBILITY

Early deployments of connected vehicle field infrastructure are likely to be installed alongside (or as part of) existing ITS equipment (e.g., dynamic message signs, CCTV cameras, and vehicle detections stations) and existing traffic signal controllers. One reason for this is that ITS

deployments are already located in areas where V2I communications are likely to be most needed and beneficial. Also, these locations provide an opportunity to leverage existing power sources, cabinet space, and backhaul communications, which will minimize deployment costs. Installation of connected vehicle field infrastructure is conceptually no different than installation of other ITS equipment. The same considerations of siting, foundations, mounting points, power, physical accessibility and security, backhaul networks, and so forth that have become standardized and accepted in ITS practice will be considerations in connected vehicle infrastructure deployments. However, the security requirements in a CVE may be more stringent than they are for a typical ITS deployment. In the case of V2V deployments, it will be necessary to install or add adequate means of communication for RSUs to the backhaul system and carefully select antennae placements on new or existing structures. Appropriate antennae placement is needed for the 300-meter line-of-sight throughout the approaching roadway to guarantee accurate V2I application support. Finally, the V2I deployment may require conducting mapping surveys of the surrounding roadway geometry to support V2I applications.

In many cases, connected vehicle infrastructure will need to be integrated with existing field equipment to enable direct data communications between the infrastructure and vehicles. One example of this is where traffic signal controllers have new connected vehicle applications integrated into their functionality to broadcast SPaT information directly to vehicles for safety and mobility applications. This type of integration of V2I equipment with existing field equipment will require the use of standard interfaces and message sets that are currently being developed by FHWA and will be provided in the *V2I Reference Implementation* document. This document will be available with the V2I Products in the near future (see Chapter 4 – V2I Products)

In many ways, connected vehicle infrastructure can be considered the next generation of ITS equipment being installed in the field with the potential to have a transformational impact on transportation operations and safety. As such, it is important to start considering V2I communications requirements and standards when new ITS equipment and traffic signal controllers are purchased and installed (see Procurement Process).

FHWA highly recommends that for any ITS equipment and traffic signal controller purchased in the future the deploying agency follow the systems engineering process and deploy the equipment in an environment that is V2I ready. This guidance defines V2I ready as a roadside installation that has the following characteristics:

- Reliable power supply
- At least one secure backhaul communication link and two secure backhaul communications links, if required by the implementing agency (one for ITS or traffic signal data and one for connected vehicle data)
- ITS equipment or controllers that are currently compliant with National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) standards and have the ability to be upgraded to support future standards (e.g., spare processor and memory)

- Electronic map or geometric description of the surrounding area
- Roadside cabinet space sufficient to house an external processor (size depends on intended application) that may be installed in the future
- Considerations and plans regarding future mounting location(s) for an RSU that will enable future V2I communications

Connected vehicle infrastructure deployment standards and practices are still in development and will continue to be so until applications have been deployed and operating for several years. Practical field experience with connected vehicle system and application deployment will continue to accumulate as new prototypes and model deployments are brought into the field. The Safety Pilot Model Deployment has significantly scaled up the field deployment of both infrastructure equipment and back-office systems relative to prior test beds and demonstrations. In addition, the USDOT has initiated more connected vehicle deployments with an emphasis on V2I and V2V applications. There is an extensive collection of connected vehicle deployment resources, at <http://www.its.dot.gov/pilots/>, that are available to the public such as :

1. Concept of Operations	2. Performance Measurement Plan
3. Safety Management Plan	4. Business Model and Financial Sustainability
5. Human Use Approval	6. Training and Education Plan

The deployments resources are in the form of reports, presentations, and webinar recordings which are excellent references for lessons learned and best practices from real-world deployments.

3.7. HARDWARE DEVICE CERTIFICATION

In conjunction with industry, the USDOT has worked to develop hardware certification processes and procedures to address the inherent risks to consumer safety, security, and privacy. There were two (2) major goals through the process:

- To work with industry to define certification needs and to develop supporting test methods and tools;
- To develop a future plan that will make certification activities self-sustaining through fees for testing; development of new requirements and test methods will be shaped by the organizations seeking those requirements.

Thus, hardware certification processes and procedures are in place along with a research plan on the USDOT's website at

http://www.its.dot.gov/research_archives/connected_vehicle/connected_vehicle_cert.htm.

3.8. RELIABILITY

Typically, deployment of V2I safety applications will augment existing devices, signs, or signals. However, given that the deployment is meant to improve safety or mitigate a design exception, operational reliability is paramount and should be incorporated into the design, procurement, and deployment.

V2I mobility applications will not necessarily backup existing schemes and will have standalone functionality.

Reliability of deployed equipment should be incorporated into the system engineering process. To ensure availability of the application, an equipment maintenance and replacement plan should be established holistically for all V2I deployments. The idea of this concept and a resulting set of maintenance requirements build on the proven systems engineering approach. The systems engineering approach is recommended as the preferred method for developing ITS projects with 23 CFR 940 (21).

Equipment and applications deployed on the National Highway System or using Federal-aid highway funds will be purchased from a qualified provider and certified through an industry-approved process when available.

3.9. USE OF RIGHT-OF-WAY

Use of right-of-way for V2I RSU follows current regulations and funding eligibility. The State DOT should consider the engineering requirements, roadway safety, and sight distances when choosing the location of the V2I RSU in the right-of-way.

Installation of connected vehicle infrastructure within the right-of-way will be allowed as long as its use has a public benefit and does not impair the safety of the roadway. Private sector secondary use may be approved by the FHWA Administrator under 23 CFR 1.23(c), as long as: (1) it is determined to be in the public interest; (2) it does not interfere with or degrade free and safe flow of traffic or the current and future primary safety and mobility applications; and (3) the private application will be opt-in and the highway user will be able to disable it at any time, at no cost to the user.

Private use arrangements are subject to 23 U.S.C. 156 and require the State to charge the fair market value for non-highway use or to obtain an exception from FHWA based on “a social, environmental, or economic purpose” (23 U.S.C. 156(b) and 23 CFR 710.403(d)). For Interstate right-of-way use, an airspace agreement is necessary (23 CFR 710.405(d)). The Federal share of net income from the revenues obtained by a State from the use of the right-of-way should be used by the State for title 23 projects, preferably for deployment and operation of the V2I network.

For Federal purposes, messages displayed within a vehicle or on a personal device are not considered advertising under the Federal Highway Beautification Act.

3.10. ALLOWANCE OF PRIVATE SECTOR USE

FHWA supports the ability to maximize the possibility of private investment to leverage costs for deployment and operations. Public owners and operators of infrastructure communication systems (fiber optics, radio relay, etc.) can allow off-public right-of-way private sector use of the system for V2I communication as long as there is a public sector benefit. This should include the following:

- There is a public sector benefit of the V2I RSU;
- The private sector use does not interfere with or degrade the primary safety and mobility applications;
- The private sector application will be opt-in by highway users, and highway users will be able to disable the application at any time, at no cost to the user;
- The roadway facility owner and/or public owners and operators of the infrastructure system are not charged for any private sector use.

Public owners and operators of the infrastructure communication system may use, for example, a privately owned RSU to:

- Control traffic management signals and/or devices;
- Monitor roadway traffic performance;
- Distribute security credentials to vehicles, devices, or applications as needed;
- Provide traveler information to vehicles through V2I communications.

The cost associated with installation and operation of private sector use or components may be eligible for Federal-aid beyond the operation of the communication backhaul.

3.11. DESIGN CONSIDERATION FOR FACILITIES

V2I applications may be used to mitigate safety and operational impacts that arise due to substandard geometric features of highways. This can be done at the network level or as part of a design exception. Therefore, the minimum design standards can be modified to take into account the safety and mobility benefits.

To operate in coordination with other deployments, deployed equipment needs to be interoperable and coordinated with other modes of transportation (e.g., light- and heavy-duty vehicles, transit systems, and railroad crossings). To the maximum extent possible, all devices and applications deployed by jurisdictions and modes should leverage this technology between the transportation entities and should not be standalone deployments.

Projects to construct or reconstruct highways should be designed in a manner that accommodates the concurrent or possible future installation of V2I RSE.

3.12. USE OF EXISTING STRUCTURES AND OTHER INFRASTRUCTURES

Installation of connected vehicle equipment on existing structures and infrastructure will be allowed as long as its use has a public benefit and does not create potential safety issues. Private sector secondary use is permissible as long as it complies with the Use of Right-of-Way section in this guidance. Designers should consider how V2I technologies will affect pedestrians, bicyclists, and other non-motorized users within the highway right-of-way; how V2I technologies may affect access to transit services; and how V2I technology can enhance livability.

3.13. USE OF PUBLIC SECTOR FLEETS (INCLUDING INCIDENT RESPONDER VEHICLES)

Depending on specific program requirements, Federal-aid highway funds can be used to procure components that enable V2I applications that are installed on public sector vehicles. This includes all the components associated with the collection and dissemination of data from the vehicle to the infrastructure, as well as information dissemination from the infrastructure to the vehicle. Federal-aid funds can also be used to procure infrastructure-based components that enable V2I applications. This includes, and is not limited to, RSE and components installed in maintenance garages and traffic and emergency operations centers. Instrumenting private contractor equipment performing maintenance or response or providing work zone safety capabilities can be federally funded as long as it provides a public benefit and the public sector retains ownership and control of the V2I equipment.

To achieve interoperability, all of the above components will need to comply and be consistent with connected vehicle architecture and standards. Federal funds cannot be used for maintenance of any of the components described above unless identified in the equipment maintenance and replacement plan (see Reliability).

The applications used on public fleets should comply with any guidance and recommendations developed that pertain to demands on the driver's attention with respect to the collection of data (e.g., recording current road conditions) and presentation of information within the vehicle.

Through the system design process and the implementation of the applications, V2I messages should comply with CVRIA and BSM standards as stated in the NHTSA V2V Communication rulemaking. Messages should be prioritized in a manner that considers the immediacy and urgency of the message and its consequence (e.g., safety messages would take priority over mobility and environment messages). The applications deployed on public sector fleets should also be consistent

and integrated with other V2I deployments on the broader vehicle fleets (e.g., private sector vehicles).

Although the ability of first responders to preempt traffic signals is an important safety application, its unauthorized use could have serious mobility implications. If this application is deployed, it should be done in concert with guidance to operators of vehicles with the capability to preempt, highlighting the negative impacts of misuse, when it should or should not be used, and disciplinary consequences of misuse.

3.14. PROCUREMENT PROCESS

Quality procurements for the assets that support CVEs will enable consistent, secure, and interoperable implementations. A generation of ITS deployment has provided many agencies with more mature practices for procurement. These practices can guide CVE procurements.

Evidence from hundreds of evaluation documents point to proactive stakeholder engagement as a determinant for deployment success. The key theme of stakeholder engagement is one that runs through the course of the entire procurement process, as the procurement should satisfy the needs of varied entities affected through the V2I deployment.

Several actions are key to quality procurements:

- Identify the existing assets that are candidates for modification to reduce the costs for delivery of power and communications to the deployment location. Whether in a rural or an urban location, there are likely various assets that are “owned” by different entities. Gaining information on the assets that are deployed, their operating capabilities, their supporting infrastructure (including mounting structures, power, and communications), and the provisions for maintaining the “legacy” assets will quickly focus the selection of candidate locations.
- Consult the ITS Costs Database for comparisons and ranges of unit and system costs. This database is fed from ITS program evaluation reports from various sectors on implementations of ITS. Much of the information generated in the ITS Costs Database originates with USDOT model deployments and field operational tests. As connected vehicle test beds and pilot sites proliferate, unit cost information will be added to this database.
- Consult with the agencies that manage the statewide acquisition of information technology products to streamline the acquisition of connected vehicle assets (similar to procuring other ITS assets). Since most people outside the transportation community are not aware of connected vehicles, deployers will be expected to provide basic education and training on the technology and how it would benefit the public agencies. FHWA is a resource for providing the basic information and may be available to provide direct support for engaging with the IT investment authorities.

- Apply the specifications that are produced by the USDOT as the basis for amending State or local qualified products lists. Vendors and solution developers are most effective when there is less variation in the specifications toward which they are building. Establishing State or local qualified products lists introduces a level of rigor that better secures the interoperability among agencies working in the same geographic area and locations far from the implementation considered by the agency.
- Modify existing guides for project development to include connected vehicle assets as part of the project cost estimation. Amend the project development guide sections for ITS assets to feature the connected vehicle assets. Allow for contingencies consistent with other ITS roadside assets like dynamic message signs. Project cost estimation should consider the costs for all of the systems engineering components articulated in various guides available through FHWA. One such resource is *Systems Engineering for Intelligent Transportation Systems* available at <http://ops.fhwa.dot.gov/publications/seitsguide/index.htm>. FHWA will be developing new reference materials for project cost estimation.
- Apply the *Connected Vehicle Footprint Analysis* produced by AASHTO to consider the typical profile and plan view drawings that could be applied for developing implementation plans. The plans will need to reflect the assessments made previously on the existing assets and supporting infrastructure. Design guides should be modified to incorporate elements of the AASHTO examples to standardize drawing plans.
- Establish test procedures and systems acceptance methodologies that minimize the risk to the agency. Ensure that during systems acceptance, data produced from the locations are not the sole possession of the design-build contractor, if one is used, but that the data can be validated by the agency working through an independent party.
- Coordinate with the agency's asset management unit to maintain accurate records of when items were deployed. This establishes a baseline for determining the lifecycle of the units. This will support the agency's efforts to develop appropriate funding plans to sustain system operation over time.
- Establish an operations and maintenance plan for the deployed system. Similar to the initiation of the CVE implementation, the choices are to contract with design-build entities or to work with a turnkey provider. There may be advantages to consider with the type of operations and maintenance plan in delivering staff with appropriate technical expertise, responsiveness in repair once the environment is in an operational State, and flexibility in obtaining support services through a number of providers.

3.15. LEGACY SYSTEMS AND DEVICES

Legacy systems and devices may be owned and operated by public agencies, private companies, or the general public. This guidance addresses those systems and devices that are under the

jurisdiction of public agencies. The principles apply to other legacy systems and devices and may be applied through other agreements, coalitions, and similar cooperative efforts.

Legacy systems or devices critical to the function of active safety applications should be retrofitted or replaced for the V2I safety application to continue to perform its job. Other legacy systems and devices may be augmented by V2I safety applications intended to improve safety or mitigate a design exception. Similarly, legacy systems and devices may support or be supplemented by other V2I applications. In these instances, retrofitting or replacing legacy systems or devices may not be required for the V2I applications to provide benefits. However, support for V2I and other connected vehicle applications and functions should be considered as these legacy systems and devices are upgraded and replaced.

The systems engineering process should be used in establishing equipment maintenance and replacement plans for legacy systems. For replacement systems using Federal-aid funding, the system engineering process should be used per the requirements in 23 CFR 940. Among the issues to be considered in the system engineering analysis are: the functionality necessary to support V2I application requirements, the number of devices affected, the useful life of equipment and lifecycle costs, and processes for replacing equipment.

3.16. COMMUNICATION TECHNOLOGY

Selection of the V2I communication technology will be based on a systems engineering analysis and consistent with application interoperability across the nation. The V2I communication technology will depend on the V2I and V2V application; however, it is vital the communication media comply with the NHTSA V2V communication rulemaking. The important factors when considering V2V communications technologies are the capability of V2V onboard units (OBUs), national interoperability, certified application support, and the technology's attributes in meeting the needs of the application, such as the timeliness or response of the communications, the tolerance for errors in communication, the ubiquity of the application, or hardware installation requirements.

3.17. DSRC SERVICE LICENSING

On December 17, 2003, the FCC adopted a Report and Order establishing licensing and service rules for the DSRC service in the ITS radio service in the 5.850 to 5.925 GHz band (5.9 GHz band). The DSRC service involves V2V and V2I communication to protect and enhance the safety of the traveling public. The band is also eligible for use by non-public safety entities and for private commercial operations. However, the safety applications always have primary status over non-safety applications. Roadside infrastructure is licensed to both public safety and non-public safety entities pursuant to 47 CFR Part 90, while OBUs are licensed by rule (i.e., no individual license is required) under 47 CFR Part 95.

With respect to roadside infrastructure, the National Telecommunications and Information Administration (NTIA) authorizes the use of this frequency spectrum for governmental entities, while the FCC issues licenses for the private sector, based on each applicant's area of operation (i.e., by county, State, multi-State, or nationwide). Approved applicants will each be granted a non-exclusive license for the geographic area requested. Given the likelihood of cross border and/or overlapping geographic area issues, applications, and potential efficiencies, a high level of State and local jurisdictional cooperation and coordination across these boundaries will be necessary.

Besides State and local governmental entities and non-public safety entities, a wider group can hold an authorization to operate RSUs in the DSRC 5.9 GHz band—specifically, entities meeting the requirements of 47 CFR 90.33 and 90.35 of the FCC Rules. Entities engaged in the operation of a commercial activity can receive authorizations to provide commercial mobile radio service or to operate stations necessary for transmission of communications (e.g., toll collection and parking guidance). Further, it should be noted that the licensing requirement only applies to equipment used for transmission; equipment designed and operated only to receive does not require siting licenses.

Although safety communication has precedence, identification and removal of interfering non-safety signals could be problematic, particularly if the interfering deployment was licensed and sited first. FHWA recommends that once an application deployment is identified in the planning process, site licensing should be undertaken. To this end, a guide to DSRC licensing is being developed for use by public agencies (see details in section 4.4 Guide to Licensing DSRC RSUs).

3.18. DATA CONNECTION AND LATENCY

Data connection and latency are key factors in the V2I implementation to improve mobility and further enhance safety through interaction with the road infrastructure. DSRC allows for communication directly between vehicles (i.e., V2V) as well as between vehicles and infrastructure (i.e., V2I or I2V) with low latency. But, DSRC is a radio-based technology with a limited range of 300 meters. For optimal performance, it requires uninterrupted line-of-sight between the transmitter and receiver. Therefore, the key infrastructural features and aspects of deployment may be fundamentally different for the same application using different communications technology (e.g., solely DSRC, DSRC and cellular, Wi-Fi, satellite, and Internet). In many cases, the applications and/or radio will be capable of selecting the best communication mode to use at any time.

However, a reliable data connection and low latency should be maintained to ensure a safe and reliable CVE. The reliable data connection should be highly available based on three key principles:

- 1) Elimination of single point of failure
- 2) Reliable crossover
- 3) Detection of failures in real time

The low latency will be based on the communication media; however, it should be measured from end to end or between the originating and the responding application.

3.19. PRIVACY

The USDOT takes privacy very seriously. We are committed to supporting deployment of a CVE that protects consumer privacy appropriately while still enabling this important safety, mobility, and environmental technology to achieve its expected benefits. With this guidance, the USDOT emphasizes that deployment of V2I technologies and applications should be guided by the Fair Information Privacy Principles (FIPPs), which are based on tenets of the Federal Privacy Act of 1974 and mirrored in the laws of many U.S. States. The principles include:

- **Transparency:** Ensuring that consumers have information about the data being collected and transmitted by the V2I system and how that data will be used and shared
- **Individual Participation and Redress:** Ensuring that consumers have a reasonable opportunity to make informed decisions about the collection, use, and disclosure of their personally identifiable information (PII) or other data that may be used to identify them directly or indirectly; reasonable access to their PII; and the opportunity to have their PII corrected, amended, or deleted, as appropriate
- **Purpose Specification:** Clearly defining and articulating the purpose(s) for which the V2I system collects, uses, maintains, or disseminates specific data elements, such as basic safety functions as well as potential mobility, environmental, or commercial applications
- **Data Minimization:** Establishing criteria based on the system's purpose to limit the collection of data to what is necessary to accomplish that purpose and limiting the retention of any information for the same purpose
- **Use Limitation:** Ensuring that consumers' data will not be used for purposes incompatible with the specified purposes
- **Data Quality and Integrity:** Establishing and enforcing data quality and integrity requirements consistent with the purposes of the system and data collection throughout the data lifecycle and in all associated uses
- **Security:** Explaining what physical, technical, and procedural measures system administrators will take to protect collected data
- **Accountability and Auditing:** Establishing processes to verify and validate the operationalization of the privacy risk management controls, addressing deficiencies, and notifying the public

FHWA will work to identify and disseminate data privacy best practices and new technical or policy controls, as applications and the V2I technologies and systems develop and consistent with V2V privacy approaches and practices.

3.20. DATA ACCESS

In general, Federal law does not assign ownership, access, and use limitations to broadcast data. As a result, the USDOT and FHWA do not currently have a specific policy assigning data ownership or limiting access to BSM data.

Access to data for use in developing mobility, environmental, and other applications including commercial applications, must be designed to protect consumer privacy. To protect consumer privacy and enhance consumer acceptance, V2I applications should limit use and broadcast of data that could impact privacy where possible and implement appropriate privacy and controls. Two critical controls directly relevant to data access are transparency and consent. Consistent with the USDOT's Connected Vehicle Privacy Principles, public and private sector application developers should ensure that consumers understand and, for opt-in applications, consent to the collection of any sensitive personal data associated with their participation in the V2I environment. FHWA is evaluating these issues and seek to publish best practices guidance on data access and data privacy in the V2I system compatible with the privacy model for V2V applications in the future.

3.21. MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES

The USDOT is evaluating RSE communication with DSRC and/or cellular devices that allow vehicles to receive information from the infrastructure and to update their security credentials. It is possible for the RSE to be co-located with infrastructure elements such as road signs and traffic signals. Thus, the infrastructure will be required to maintain the standards set forth in the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (22). The MUTCD is incorporated by reference in 23 CFR 655(f) and is the national standard for all traffic control devices installed on any street, highway, bikeway, or private road open to public travel in accordance with 23 U.S.C. 109(d) and 402(a).

It is not expected that every roadside sign, signal, or pavement marking will be replicated or communicated within the vehicle. The role of the RSE will be to provide information to the OBU in sufficient detail and accuracy to convey that information in a manner consistent with the traffic control devices. While the traffic control devices are governed by the provisions of the MUTCD, the medium of communication and message composition within the vehicle are not addressed in the MUTCD. However, the information conveyed to the driver cannot contradict information conveyed by the signs, signals, and markings on and along the road.

Generally, communication from vehicles to the RSE will not directly affect the display or operation of a changeable traffic control device, such as a traffic signal or changeable message sign. However, the generic information received, from V2V enabled devices, by the RSE can be used by the agency to make decisions about adjustments to the traffic control devices in response to the data. Therefore, the decision about what information is displayed on a traffic control device will continue to be made by the jurisdictional agency. In the case of an actuated traffic control

device as a result of communication from the vehicle, the message or operation of that device will be determined by the agency in the design of the device. That is, the vehicle will not affect a unique message or operation of an actuated device, but can actuate a display or operation that has been pre-programmed into that device.

3.22. USING PUBLIC-PRIVATE PARTNERSHIPS (P3s)

To the extent possible, P3s and other commercial relationships should be considered for deployment. However, such arrangements should ensure that the “commercial” applications protect the public interest, do not compromise the safety and mobility objectives, provide for safe maintenance practices, and hold the jurisdiction harmless due to lack of both public and private services. These arrangements should be established through P3 agreements that guarantee the precedence of the V2I safety and mobility applications, including the ability to terminate the relationship in the event that the private sector use degrades the V2V or V2I environment. The public owner or operator of the V2I infrastructure should also ensure that the arrangement produces a net lifecycle benefit to the public and value for the transportation agency. Additionally, such deployments should be compatible with the connected vehicle security system; support the distribution, receipt, and use of certificates in support of message authentication approaches as needed; and implement the privacy protections and controls of the CVE.

Current FHWA policy allows State DOTs to use Federal-aid funds in innovative long-term contracts with private developers under certain conditions. In such agreements, the State grants exclusive rights (a concession) to a developer (concessionaire) who assumes responsibility for the highway’s construction, operations, and upkeep. In the case described here, the developer would take responsibility for the deployment and operation of the V2I system.

P3 concession contracts often allow the concessionaire to collect and retain revenue from tolls; however, in this instance, tolls would not be applicable. The “business model” of V2I P3 is different in the sense that, instead of the private entity receiving payment from the highway user for access to a toll lane or facility, revenue to the private entity would most likely come from use of the communications channel to generate fee-for-service opportunities or advertising revenue.

Additional information on transportation P3s can be found at <http://www.fhwa.dot.gov/ipd/p3/index.htm>.

CHAPTER 4. V2I PRODUCTS

This chapter summarizes V2I products that will be available to assist FHWA staff and transportation system owners and operators with deploying V2I technology. These products are an essential supplement to this policy guidance. As of this writing, the following products are currently under development to facilitate an effective path toward a CVE:

- Connected Vehicle V2I Systems Engineering Guidance
- Report on Incorporation of Connected Vehicles into the Transportation Planning Process
- Desk Reference and Tools for Estimating the Local, Regional, and State Economic Development Benefits of Connected Vehicles to Infrastructure Deployments
- Guide to Licensing DSRC RSUs
- V2I Message Lexicon
- Near-term (0- to 5-year) V2I Transition and Phasing Analysis
- V2I Pre-deployment Guidance
- Connected Vehicle Training Resources

These products are separate reference documents and/or online software applications with a specific focus on V2I deployments. Since the products are still under development, this chapter describes the products and projected availability date for each. The “End Product” is the summary of the product that will be made available to the end user and “Product Availability” is the projected timeframe for when the product will be available to the end user. The V2I products will be available at this Internet hyperlink: www.its.dot.gov/V2I.

4.1. CONNECTED VEHICLE V2I SYSTEMS ENGINEERING GUIDANCE

The *Connected Vehicle V2I Systems Engineering Guidance* is an interim technical assessment of prior and ongoing connected vehicle research and development activities for early adopters at the State and local government levels. The technical assessment will consider the following:

1) Planning and Institutional Requirements

- Analysis to establish the needs of the State and local agencies
- Testing and deployment objectives for State agencies
- Deployment options for the agencies

2) Interoperability

- Among V2I and V2V technology
- Between transportation modes and regions
- With message standards, types, and extensibility

- Message authentication

3) **Deployment and Licensing of DSRC Spectrum**

- RSU siting and co-location with existing ITS infrastructure
- Coordination with adjacent and overlapping jurisdictions
- Interference from private and commercial applications

4) **Applications**

- Appropriateness at various market penetration rates
- Interaction with legacy systems and devices
- Consideration in utilizing transportation funded infrastructure for non-safety and non-mobility applications

5) **Reliability**

- Equipment maintenance, patches, upgrade, and a replacement plan (both software and hardware)
- Design considerations for facility
- Impact of fault and failure modes
- Non-malicious and malicious software and hardware attacks
- Secondary impact of failure to or from legacy transportation network

6) **Communication Technology Selection**

- DSRC, cellular, and other media
- Media access, channel use, communication security, and privacy
- Data rates and latency requirements for specific applications

End Product: The *Connected Vehicle V2I Systems Engineering Guidance* will address critical milestones in connected vehicle penetration and system maturity that will provide connected vehicle applications along with a readiness checklist.

Product Availability: The products are projected to be available in early 2017.

4.2. REPORT ON INCORPORATION OF CONNECTED VEHICLES INTO THE TRANSPORTATION PLANNING PROCESS

The objective of incorporating connected vehicles into the transportation planning process is to identify different types of planning products and processes that should be considered for connected vehicles and the nature of the situation (e.g., the specific objectives and outcomes associated with considering connected vehicles in the various processes and products). Also, the process will identify the roles and responsibilities of the different types of agencies and other stakeholders who will be responsible for those products and processes.

The transportation planning process will analyze findings that facilitate connected vehicle planning by States, MPOs, and local agencies. The process will consider four types of analysis:

- 1) Identification of how connected vehicles should be considered in transportation planning processes and products under a variety of circumstances. The planning process and products will address the following:
 - Statewide and regional ITS deployment program or strategic plans
 - Statewide and regional long-range transportation plans
 - Statewide and regional ITS architectures
 - Statewide and regional transportation improvement programs (TIPs)
 - Congestion management plans
 - State transportation asset management plans
 - State strategic highway safety plans
- 2) Identification of the need for new or enhanced tools, techniques, and data to support various connected vehicle planning activities and approaches for how to meet those needs
- 3) Development of a number of illustrative scenarios of connected vehicle planning, based on real-world planning environments, that highlight the various ways that connected vehicles can be addressed, including how new or enhanced tools, techniques, and data can be applied to confront specific connected vehicle issues:
 - Reflect a variety of connected vehicle applications such as V2V, V2I, and vehicle-to-device (e.g., connected handheld devices utilized by pedestrians)
 - The type of lead agency (e.g., State DOT, MPO)
 - Size of the agency and character of the planning area (e.g., a large urban MPO with extensive traffic congestion, a small urban MPO with limited congestion and extensive rural, intercity highways)
 - Planning horizon (e.g., long-term (5 to 20 years) and short-term (0 to 5 years))
 - Statewide and regional connected vehicle deployment or strategic plan
 - State and regional long-range transportation plan
 - State and regional TIP
 - State and regional ITS architecture
- 4) Skill, expertise, and other workforce capabilities needed by transportation planning agencies to effectively include connected vehicles in their relevant planning processes. Identification of the roles and responsibilities of the stakeholders and organizational and workforce skills, expertise, and capabilities needed to carry out connected vehicle planning. For each required skill, expertise, or capability, the following are identified:
 - The relative priority or urgency in light of the status of connected vehicle technology development and adoption and how soon the technology will need to be incorporated into various planning processes and products
 - Alternative approaches for acquiring the needed skills (e.g., development of in-house staff capabilities, partnering with other agencies, utilizing consultants), taking into account different types of planning agencies and their varying size and resources
 - Specific training needs

- Linkages with existing training transportation planning professional capacity building resources available to various sorts of planning agencies (e.g., whether there are existing training courses and guidance documents that would logically be expanded to include connected vehicle topics)

End Product: A desk reference guide and a report that offers practitioners a menu of connected vehicle options for incorporating the technology into transportation planning processes.

Product Availability: The products are projected to be available in early 2017.

4.3. DESK REFERENCE AND TOOLS FOR ESTIMATING THE LOCAL, REGIONAL, AND STATE ECONOMIC DEVELOPMENT BENEFITS OF CONNECTED VEHICLES TO INFRASTRUCTURE DEPLOYMENTS

This product will estimate the potential local, regional, and State economic benefits and costs associated with integrating connected vehicles into infrastructure applications, including economic development benefits. The end result will be a desk reference and tools for practitioners to assess the economic benefits, costs, and tradeoffs associated with implementing connected vehicle infrastructure on a project, program, or regional area and in an easily updatable format.

The study includes the following tasks:

- 1) Literature review
 - Covers various perspectives for estimating benefits, economic impact, economic development, and benefit and cost. It also describes different modeling methods available
 - Reviews the benefits available in the connected vehicle literature, starting with the direct impacts on roadway users
 - Reviews economic analysis approaches that have been applied at the State level, using available synthesis studies as references
- 2) Quantification of the potential local, regional, and State economic benefits associated with integrating connected vehicle infrastructure applications, including economic development benefits.
- 3) Desk reference and tools for local and regional planners to assess the economic benefits and tradeoffs associated with implementing connected vehicle infrastructure on a project, program, or regional area and in an easily updatable format:
 - The desk reference and tools will include simplified methods for users to update and adjust assumptions

- The desk reference and tools can be used in the calculation of all raw data inputs and outputs

End Product: A final desk reference tool for estimating local, regional, and State economic development benefits of connected vehicles to infrastructure deployments.

Product Availability: The product is projected to be available in early 2017.

4.4. GUIDE TO LICENSING DSRC RSUs

The objective of this guide is to outline the process and requirements for obtaining DSRC RSU licenses from the FCC, as well as the terms and conditions for maintaining licenses over their lifecycle. The lifecycle includes planning, deployment and commissioning, monitoring, remediation, optimization, and decommissioning of RSUs. The goal is to make the licensing process and requirements transparent and accessible for public or private organizations seeking to deploy V2I technology.

The guide will focus on the following from the perspective of a deployer or implementer:

- 1) **Administration:** The process for obtaining a license, addressing interference, coordinating between adjacent jurisdictions (the important topics and requirements to address), and other topics deemed necessary to administer a site
- 2) **Management:** Guidance on license maintenance, interference identification, necessary equipment or services for an agency to have available to detect interference, and other topics deemed necessary to manage a site over time
- 3) **Field:** Significant parameters and guidance on design, siting, placement, location selection, ensuring optimal performance of the radio, testing, and certification of equipment
- 4) **Rules and Regulations:** Guidance on the roles and responsibilities of an agency regarding the FCC rules and regulations and the identification of the limitations or places where the regulations might evolve and impact an agency in the future

End Product: A final guide document will detail the DSRC licensing process, from the perspective of a deployer or implementer, with a focus on administration, management, field, and rules and regulations.

Product Availability: The product is projected to be available in early 2017.

4.5. V2I MESSAGE LEXICON

The V2I message lexicon will explain the concepts and definitions for V2I communication messages. The lexicon identifies the contents of a V2I message, how the message is constructed, how the message relates to applications, and how the message relates to deployments. The V2I message lexicon will show the relationships among the CVRIA, the National ITS Architecture,

the various standards needed to define the V2I message, and the organizational entities that provide content or services to the V2I messages. The document will discuss the following:

- **How V2I Messages Relate to Applications:** A sample set of scenarios will be introduced including the types of information needed for each scenario. The relationship between the information needed by an application and V2I messages will be explained in this section
- **How V2I Messages Relate to Deployments:** A list of issues to consider and a general systems engineering lifecycle to use as guidance

End Product: The document will describe the various V2I message sets and show the relationship among the CVRIA, the National ITS Architecture, the various standards needed to define V2I messages, existing device specifications, and the organization entities that provide content or services to the V2I messages.

Product Availability: The product is projected to be available in early 2017.

4.6. NEAR-TERM (0- TO 5-YEAR) V2I TRANSITION AND PHASING ANALYSIS

The objective of this guide is to conduct analyses regarding the next steps for phasing of V2I applications, infrastructure, technologies, and systems. The analyses will include the following:

- 1) **Applications Prioritization Process:** A design, format, and methodology for a process that can be used by State and local implementers in identifying and sequencing their near-term (0 to 5 years) and longer-term (up to year 2040) priorities for V2I applications deployment. The process will be based on criteria that support decision makers in identifying their priorities, which include conditions and characteristics of various prototypical deployment contexts (e.g., large urban, small urban, and rural). There will be an emphasis on the sequence of investments and priorities that will result in the benefits during the initial years of deployment before there is a concentration of connected vehicles. The process will support the broader transportation investment planning and programming activities that State and local agencies perform. The process will be responsive to the varying circumstances of the different State DOTs, MPOs, counties, and municipalities that carry out such planning and programming, including variations in the size and character of the planning area (e.g., urban corridor, urban area, rural or intercity corridor, statewide, and interstate corridor).
- 2) **Process and Tool for Phasing V2I Infrastructure Deployments:** A process for prioritizing the deployment of V2I infrastructure applications that can be used by State and local transportation agencies to determine the appropriate sequencing of V2I infrastructure implementation, with particular focus on phasing over the initial 5 years of deployment. The process will build on the preliminary investigations of V2I

infrastructure components from the AASHTO *National Connected Vehicle Field Infrastructure Footprint Analysis*. The process will consider the relevant findings from ongoing research at the Southeast Michigan Test Bed. The prioritization process will use examples by State and local transportation agencies around the country as part of their connected vehicle and broader transportation investment planning and programming activities. The process and tool will be responsive to the varying circumstances of the different State DOTs, MPOs, counties, and municipalities that carry out such planning and programming, including variations in the size and character of the planning area. The process will consider V2I safety, mobility, road weather, and environmental applications that have been identified to date, including those in the CVRIA.

- 3) **Lifecycle Cost for V2I Components:** The lifecycle costs for V2I components will build on the AASHTO *National Connected Vehicle Field Infrastructure Footprint Analysis* and consider relevant cost or other data from Connected Vehicle Test Beds, including the Southeast Michigan and Affiliated Test Beds. The costs will reflect the entire lifecycle of V2I deployments, from design, through implementation and operation, to replacement. At a minimum, the lifecycle costs will contain the following:
- Identification of the intended uses and users of the Lifecycle Costs for V2I Applications Components
 - Identification of the V2I applications to be supported
 - Identification of the infrastructure necessary to support the V2I applications, including field and center and hardware and software elements
 - Consideration of all relevant capital: Operations and maintenance (O&M), replacement, and annualized costs
 - Within each of the capital, O&M, and annualized costs, further disaggregation of costs into “one-time” enabling investments (e.g., transportation management center systems) and incremental investments (e.g., the cost of adding an additional RSE to a deployed system)
 - Consideration of how the market maturity of V2I devices will impact costs over time, from an initial condition characterized by a limited number of suppliers producing relatively low volumes of still-evolving designs to a mature marketplace characterized by greater competition, higher production volume, and more less-rapidly changing designs
 - Consideration of key information needed in support of the costs to facilitate their appropriate interpretation and use
- 4) **Scenario Development:** A synthesis of all cost elements to produce a set of scenarios that provide agency-based examples of prioritization and the development of a strategic phase-in and transition approach using the tool. In addition to the existing AASHTO footprint scenarios, there will be up to five new scenarios developed based on the most likely near-term applications that will be deployed in a variety of deployment settings. These scenarios will provide specific guidelines and tips for siting, design, or steps an

agency can take at little to no cost to prepare for future connected vehicle implementations.

End Product: A customizable spreadsheet-based tool to produce values for the full lifecycle costs of a V2I deployment over the first 5 years.

Product Availability: The products are projected to be available in mid-2017.

4.7. V2I PRE-DEPLOYMENT GUIDANCE

The objective of the V2I pre-deployment guidance is to assist State and local transportation agencies with decision-making and prioritization of implementing V2I safety applications. The pre-deployment guidance will present a series of questions to help users determine whether they should consider a V2I safety application deployment for specific uses and locations. The initial pre-deployment guidance will focus on the following V2I applications:

- Red Light Violation Warning
- Curve Speed Warning
- Stop Sign Gap Assist
- Reduced Speed Zone Warning
- Spot Weather Information Warning
- Stop Sign Violation Warning
- Railroad Crossing Violation Warning
- Oversize Vehicle Warning

End Product: The initial pre-deployment document will present a series of questions to help users determine whether to deploy a given V2I safety application.

Product Availability: The product is projected be available in mid-2017

4.8. CONNECTED VEHICLE TRAINING RESOURCES

This white paper will provide free USDOT connected vehicle training resources that are or soon will be available. The material ranges from instructor-led workshops, webinars, presentations, ITS standards modules, and videos. Also, there are three training resources by a non-USDOT organization in connected vehicle wireless communication, a certification curriculum for connected vehicle professionals, and a software tool that integrates drawings and database tools with the CVRIA.

This training material is sponsored by the USDOT's ITS Professional Capacity Building (PCB) Program, which is in the process of developing a comprehensive training and education implementation plan for connected vehicle professionals (e.g., transportation operations managers, engineers, and technicians) over the next 5 years. These materials will be developed

by the USDOT or its partners in learning and professional development, such as AASHTO, the Institute of Transportation Engineers (ITE), ITS America, the Society of Automotive Engineers (SAE), and others.

As more training and education resources become available, they will be added to the ITS PCB website at pcb.its.dot.gov. Anyone interested in the training can also receive announcements of upcoming webinars on ITS topics by sending an email to T3@dot.gov with the subject line “Add to Email List.”

End Product: This white paper will describe several connected vehicle training resources and the target audiences, as well as provide the Internet hyperlink to the resources.

Product Availability: The products are projected to be available in early 2017.



CHAPTER 5. APPENDICES

5.1. REFERENCES

1. **National Highway Traffic Safety Administration.** Depiction of Priority Light-Vehicle Pre-Crash Scenarios for Safety Applications Based on Vehicle-to-Vehicle Communications. *NHTSA Website*. [Online] 2013. (DOT HS 811 732).
<http://www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2013/811732.pdf>.
2. **Federal Highway Administration.** Crash Data Analyses for Vehicle-to-Infrastructure Communications for Safety Applications. *FHWA website*. [Online] 2012. (FHWA-HRT-11-040). <http://www.fhwa.dot.gov/publications/research/connectedvehicles/11040/11040.pdf>.
3. **National Highway Traffic Safety Administration.** Federal Motor Vehicle Safety Standards - V2V Communications. *NHTSA website*. [Online] 2016. [Cited: March 31, 2015.] (Docket No. NHTSA 2016-0126).
4. **Federal Highway Administration.** Transit Vehicle-to-Infrastructure Applications: Near Term Research and Development. *National Transportation Library Website*. [Online] 2014. (FHWA-JPO-14-129). <http://ntl.bts.gov/lib/54000/54000/54075/14-129.pdf>.
5. **USDOT Intelligent Transportation Systems - Joint Program Office.** Connected Vehicle Technology Standards. *USDOT ITS-JPO website*. [Online] 2014.
http://www.its.dot.gov/connected_vehicle/connected_vehicle_standards.htm#sthash.DguPOA14.dpuf.
6. **USDOT Intelligent Transportation Systems.** ITS Standards Program: Connected Vehicle Reference Implementation Architecture. *USDOT ITS-JPO*. [Online] 2014.
<http://www.standards.its.dot.gov/DevelopmentActivities/CVReference> .
7. **Federal Highway Administration.** Transportation Systems Management and Operations: Operating Cost Eligibility Under the Federal-Aid Highway Program. *FHWA Website*. [Online] 2013. http://ops.fhwa.dot.gov/travelinfo/resources/ops_guide.htm.
8. **Federal Highway Administration.** Highway Safety Improvement Program. *FHWA website*. [Online] 2012. <http://www.fhwa.dot.gov/map21/guidance/guidehsip.cfm> .
9. **Federal Highway Administration.** Highway Safety Improvement Program MAP-21 Interim Eligibility Guidance. *FHWA website*. [Online] 2012.
<http://www.fhwa.dot.gov/map21/guidance/guideship.cfm>.

10. **Federal Highway Administration.** National Highway Performance Program Implementation Guidance. *FHWA*. [Online] 2012.
<http://www.fhwa.dot.gov/map21/guidance/guidenhpp.cfm> .
11. **Federal Highway Administration.** Revised Surface Transportation Program Implementation Guidance. *FHWA website*. [Online] 2014.
<http://www.fhwa.dot.gov/map21/guidance/guidestprev.cfm>.
12. **Federal Highway Administration.** Air Quality - Congestion Mitigation and Air Quality Improvement Program. *FHWA Website*. [Online] September 13, 2013.
http://www.fhwa.dot.gov/environment/air_quality/cmaq/reference/cmaq_map21/index.cfm.
13. **American Association of State Highway and Transportation Officials.** National Connected Vehicle Field Infrastructure Footprint Analysis - Applications Analysis. *AASHTO website*. [Online] 2013.
http://stsmo.transportation.org/Documents/Applications_Analysis%20v3%20july%202013.pdf.
14. **American Association of State Highway and Transportation Officials.** Connected Vehicle Infrastructure Deployment Analysis. *National Transportation Library Website*. [Online] 2011. (FHWA-JPO-11-090). http://ntl.bts.gov/lib/43000/43500/43514/FHWA-JPO-11-090_AASHTO_CV_Deploy_Analysis_final_report.pdf.
15. **USDOT Intelligent Transportation Systems - Joint Program Office.** Connected Vehicles Pilots Deployments Project. *USDOT ITS-JPO website*. [Online] 2015.
http://www.its.dot.gov/pilots/cv_pilot_apps.htm.
16. **National Highway Traffic Safety Administration.** Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications. *NHTSA website*. [Online] 2014. (DOT HS 812 014). <http://www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf>.
17. **Federal Highway Administration.** Regional ITS Architecture Guidance Document Version 2.0. *FHWA website*. [Online] 2006. (FHWA-HOP-06-112). On January 8, 2001, the USDOT published the FHWA Final Rule and FTA Policy which required ITS projects funded through the highway trust fund to conform to the National ITS Architecture and applicable standards..
<http://ops.fhwa.dot.gov/publications/regitsarchguide>.
18. **Federal Communication Commission.** Federal Communication Commission - Tower and Antenna Siting. *FCC website*. [Online] <http://www.fcc.gov/encyclopedia/tower-and-antenna-siting>.
19. **Government Printing Office.** 23 CFR 771.117(c)(21). *US GPO*. [Online] 2011.
<http://www.gpo.gov/fdsys/pkg/CFR-2011-title23-vol1/pdf/CFR-2011-title23-vol1-sec771-117.pdf> .
20. **USDOT Intelligent Transportation Systems - Joint Program Office.** Connected Vehicle Technology Certification. *USDOT ITS-JPO*. [Online] 2015. [Cited: Mach 30, 2015.] USDOT's

Intelligent Transportation Systems –

http://www.its.dot.gov/connected_vehicle/connected_vehicle_cert.htm .

21. **Federal Highway Administration.** FHWA Rule/FTA Policy. *FHWA website*. [Online] 2001. http://www.ops.fhwa.dot.gov/its_arch_imp/policy.htm.

22. **Federal Highway Administration.** Manual on Uniform Traffic Control Devices for Streets and Highways with Revisions 1 and 2. *FHWA website*. [Online] 2009. http://mutcd.fhwa.dot.gov/kno_2009r1r2.htm.

23. **Society of Automotive Engineers International.** DSRC Implementation Guide: A guide to users of SAE J2735 message set over DSRC. *SAE website*. [Online] 2010. <http://www.sae.org/standardsdev/dsrc/DSRCImplementationGuide.pdf>.

24. **Federal Highway Administration.** Air Quality - Congestion Mitigation and Air Quality Improvement Program. *FHWA website*. [Online] 2013. http://www.fhwa.dot.gov/ENVIRONMENT/air_quality/cmaq/reference/cmaq_map21/index.cfm.

5.2. DEFINITIONS

Term	Description
Aftermarket Safety Device (ASD)	A connected device in a vehicle that operates while the vehicle is mobile, but that is not connected to the data bus of the vehicle.
Backhaul	The closed network communication links between a traffic management center (or other back offices) and field installations (such as traffic signal controllers, traffic cameras, and other sensors). This could also include the link between any security manager and roadside distribution device.
Basic Safety Message (BSM)	The core data set transmitted by the connected vehicle (vehicle size, position, speed, heading acceleration, brake system status) and transmitted approximately 10 times per second. A secondary set is available depending upon events (e.g., ABS activated) and contains a variable set of data elements drawn from many optional data elements (availability by vehicle model varies). This would be transmitted less frequently. The BSM is tailored for low latency, localized broadcast required by V2V safety applications but can be used with many other types of applications.
Connected Device	Any device used to transmit to or receive messages from another device. A connected device can be sub-categorized as an OBE, ASD, vehicle awareness device, or RSE. In many cases, the connected device will be a DSRC device, but other types of communications can and are expected to be supported.
Connected Vehicle	A vehicle containing an OBU or ASD. Note that vehicles may alternatively include a vehicle awareness device, which transmits the BSM but does not receive broadcasts from other devices and cannot directly support vehicle-based applications.
Connected Vehicle Reference Implementation Architecture (CVRIA)	A set of system architecture views that describe the functions, physical and logical interfaces, enterprise and institutional relationships, and communications protocol dependencies within the connected vehicle environment. The CVRIA defines functionality and information exchanges needed to provide connected vehicle applications.
Dedicated Short-Range Communications (DSRC)	DSRC is a technology for the transmission of information between multiple vehicles (V2V) and between vehicles and the transportation infrastructure (V2I) using wireless technologies.
Intelligent Transportation Systems (ITS)	Systems that apply data processing and data communications to surface transportation to increase safety and efficiency. ITS will often integrate components and users from many domains, both public and private.

Term	Description
Interoperability	The ability of two or more systems or components to exchange information and to use the information that has been exchanged.
Latency	A measure of time delay experienced in a system, the precise definition of which depends on the system and the time being measured. For a data element in this context, latency is the time difference between the time that data value is acquired by the source and the time the message is transmitted.
National Transportation Communications for Intelligent Transportation System Protocol (NTCIP)	The NTCIP is a family of standards designed to achieve interoperability and interchangeability between computers and electronic traffic control equipment from different manufacturers.
Onboard Equipment (OBE)	This term refers to the complement of equipment located in the vehicle for the purpose of supporting the vehicle side of the applications. It is likely to include the DSRC radios, other radio equipment, message processing, driver interface, and other applications to support the use cases described herein. It is also referred to as the vehicle ITS station. When referring to the DSRC radio alone, the correct term is OBU (see below).
Onboard Unit (OBU)	A vehicle-mounted device used to transmit and receive a variety of message traffic to and from other connected devices (other OBUs and RSUs). Among the message types and applications supported by this device are vehicle safety messages, a primary subject of this standard, used to exchange information on each vehicle's dynamic movements for coordination and safety.
Original Equipment Manufacturer (OEM)	An OEM refers to the entity that originally manufactures an item that may be branded and sold by others. In the connected vehicle environment, it is commonly used to refer to automobile manufacturers.
Public-Private Partnership (P3)	P3s are contractual agreements formed between a public agency and a private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects.
Roadside Equipment (RSE)	Term used to describe the complement of equipment to be located at the roadside; the RSE will prepare and transmit messages to the vehicles and receive messages from the vehicles for the purpose of supporting the V2I applications. This is intended to include the DSRC radio, traffic signal controller where appropriate, interface to the backhaul communications network necessary to support the applications, and support of such functions as data security,

Term	Description
	encryption, buffering, and message processing. It may also be referred to as the roadside ITS station. When speaking of the DSRC radio alone, the correct term is RSU (see below).
Roadside Unit (RSU)	An RSU is a DSRC radio-equipped device that demarcates component between vehicles and other mobile devices and existing traffic equipment. The RSU can be a permanent roadside installation or temporary installation deployed to support operation around an incident, work zones, or special events. At the time of this writing, RSU version 4 is the latest specification, but is still considered to be a pre-production stage of specification. Equipment that is version 4 compliant can be upgraded to specification version 4+ and version 5 via firmware upgrade.
Signal Phase and Timing (SPaT)	In the context of this standard, SPaT is a message type that describes the current state of a signal system and its phases and relates this to the specific lanes (and therefore to maneuvers and approaches) in the intersection.
Systems Engineering	An interdisciplinary practice that focuses on how to design and manage complex projects and deployments over their lifecycles. It ensures that all likely aspects of a system are considered and integrated into a whole.
Vehicle	A self-propelled transport device, along with any attachments (e.g., trailers), that is a legal user of the transportation network.
Vehicle-to-Vehicle (V2V) Communications	A system designed to transmit basic safety information between vehicles to facilitate warnings to drivers concerning impending crashes.
Vehicle-to-Infrastructure (V2I) Communications	A system designed to transmit information between vehicles and the road infrastructure to enable a variety of safety, mobility, and environmental applications.
Vehicle-to-Infrastructure (V2I) Reference Implementation	An interface system that supports the collection, integration, and dissemination of data between infrastructure and vehicles to enable integrated, interoperable V2I safety, mobility, and environmental applications.
Vehicle-to-Infrastructure (V2I) Reference Implementation Document	This document will include the standards, specifications, and interfaces for hardware and firmware that can be used in the connected vehicle environment. The document will establish an integrated positioning, mapping, and communication environment that supports various prototyped applications. It will include safety applications developed with security and privacy as well as an application prioritization scheme as set by policy. The document is

Term	Description
	projected to be available in 2017.



5.3. SYMBOLS AND ABBREVIATIONS

Term	Meaning
AASHTO	American Association of State Highway and Transportation Officials
BSM	Basic Safety Message
CVE	Connected Vehicle Environment
CVRIA	Connected Vehicle Reference Implementation Architecture
DSRC	Dedicated Short-Range Communications
I2V	Infrastructure to Vehicle
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation Systems
MPO	Metropolitan Planning Organization
MUTCD	Manual on Uniform Traffic Control Devices
OBE	Onboard Equipment
OBU	Onboard Unit
RSE	Roadside Equipment
RSU	Roadside Unit
SAE	Society of Automotive Engineers International
SPaT	Signal Phase and Timing
TMC	Traffic Management Center
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle

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