



# CV261: Vehicle-to-Vehicle (V2I) ITS Standards for Project Managers

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## Module Description

This module is an introduction to the connected vehicle environment, with a focus on a standards-based vehicle-to-infrastructure (V2I) communications. A companion module is CV262, Vehicle-to-Vehicle (V2V) ITS Standards for Project Managers, which focuses on standards-based V2V communication.

## 1. Introduction/Purpose

### What are Connected Vehicles?

The term connected vehicles refers to applications, services, and technologies that connect a vehicle to its surroundings. A connected vehicle includes the different communication devices (embedded or portable) present in the vehicle, that enable in-car connectivity with other devices present in the vehicle and/or enable connection of the vehicle to external devices, networks, applications, and services. Applications include everything from traffic safety and efficiency, parking assistance, roadside assistance, remote diagnostics, and telematics to autonomous self-driving vehicles and global positioning systems (GPS). Typically, vehicles that include interactive advanced driver-assistance systems (ADASs) and cooperative intelligent transport systems (C-ITS) can be regarded as connected. Connected-vehicle safety applications are designed to increase situation awareness and mitigate traffic accidents through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

ADAS (Advanced Driver Assistance System) technology can be based on vision/camera systems, sensor technology, vehicle data networks, V2V, or V2I systems. Features may include adaptive cruise control, automate braking, incorporate GPS and traffic warnings, connect to smartphones, alert the driver to hazards, and keep the driver aware of what is in the blind spot. V2V communication technology could mitigate traffic collisions and improve traffic congestion by exchanging basic safety information such as location, speed, and direction between vehicles within range of each other. It can supplement active safety features, such as forward collision warning and blind-spot detection. Connected vehicles technologies are also expected to be a fundamental component of automated driving as they will allow the exchange of sensor and awareness data among vehicles, cooperative localization and map updating, as well as facilitate cooperative maneuvers between automated vehicles.

### What is Connected Vehicle (CV) Environment?

In broad terms, the CV environment consists of connected vehicles (V2V), connected V2P (individuals-person-pedestrian for P), and connected infrastructure (V2I) operating together to provide valuable services.

In order to operate together, this environment (devices) requires the use of communication technologies. For mobile devices (e.g., vehicles, pedestrians, bicycles, etc.), connectivity is provided through a range of wireless (cellular) technologies.

**Short range communications**, which provide an open network over hundreds of meters so that vehicles approaching each other at speed can communicate and inform each other of their presence and movement (example, DSRC-dedicated short-range communication medium uses RF broadcasting radio to transmit/receive messages/data in short range).



**Remote communications**, which allow devices to access centralized services, such as fleet management capabilities, regional traffic management, personalized trip information, etc. (example, NTCIP-National Transportation for ITS Protocol used for control/command of field devices such as Dynamic Message Sign (DMS) or an Actuated Traffic Signal Controller-ASC).

**Safety/Mobility applications** are also part of CV environment and they process messages/data to provide benefits through collision avoidance/injuries and travel efficiency, just to identify a few examples. ARC-IT (National ITS Architecture, now called Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT) v8.3 (2019) describes an array of these services and summarizes the vast amount of detail that has been developed to define how these systems work.

## CV Benefits/Impacts

The connected vehicle environment has the potential to significantly reduce vehicular crashes, provide operators of surface transportation systems with more timely and accurate system performance data to better manage their systems, and provide travelers with access to specific traveler information. In such an environment, each vehicle on the roadway can also potentially serve as a data collector, providing transportation planners with a wealth of real-time travel data.

## Purpose of this Module

This module introduces the connected vehicle environment and a description of the potential benefits and capabilities of a Vehicle-to-Infrastructure (V2I) environment. The module presents several V2I safety, mobility, and environmental applications and discusses the types of information that may be exchanged between the different devices that make up the V2I environment. The module then presents the ITS Standards that help support the deployment of V2I applications. The module identifies key challenges in designing and implementing a V2I infrastructure, and outlines approaches to deploying the V2I infrastructure. The companion module on V2V (Module CV 262) focuses on vehicle-based technology and V2V environment. Both modules collectively teach us how to plan, develop and implement CV applications.

It is essential that agencies use standards in deploying connected vehicle technologies to maximize the benefits from the connected vehicle environment. By taking this module, participants will learn what connected vehicle standards exist, where to find the standards, and how to use the connected vehicle standards to procure, implement and operate standards-based devices and equipment. These standards will enable interoperable V2X communication to enable implementation of CV safety and mobility, including V2I applications such as Transit Signal Priority (TSP), Curve Speed Warning, and Pedestrian in Crosswalk Warning (PCW).

## 2. Reference to Other Standards

### USDOT (US Department of Transportation)

- USDOT ITS Standards Program, <http://www.standards.its.dot.gov/>

### IEEE (Institute of Electrical and Electronics Engineers)

- IEEE 1609.0-2019 - IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture, IEEE, [https://standards.ieee.org/standard/1609\\_0-2019.html](https://standards.ieee.org/standard/1609_0-2019.html)
- IEEE 1609.2-2016 - IEEE Standard for Wireless Access in Vehicular Environments — Security Services for Applications and Management Messages, IEEE, [https://standards.ieee.org/standard/1609\\_2-2016.html](https://standards.ieee.org/standard/1609_2-2016.html)



- IEEE 1609.2a-2017 - IEEE Standard for Wireless Access in Vehicular Environments — Security Services for Applications and Management Messages – Amendment 1, IEEE, [https://standards.ieee.org/standard/1609\\_2a-2017.html](https://standards.ieee.org/standard/1609_2a-2017.html)
- IEEE 1609.2b-2019 - IEEE Standard for Wireless Access in Vehicular Environments — Security Services for Applications and Management Messages – Amendment 2—PDU Functional Types and Encryption Key Management, IEEE, [https://standards.ieee.org/standard/1609\\_2b-2019.html](https://standards.ieee.org/standard/1609_2b-2019.html)
- IEEE 1609.3-2016 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE) – Networking Services, IEEE, [https://standards.ieee.org/standard/1609\\_3-2016.html](https://standards.ieee.org/standard/1609_3-2016.html)
- IEEE 1609.4-2016 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE)-- Multi-channel Operation, IEEE, [https://standards.ieee.org/standard/1609\\_4-2016.html](https://standards.ieee.org/standard/1609_4-2016.html)
- IEEE 1609.11-2010 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE)-- Over-the-Air Electronic Payment Data Exchange Protocol for Intelligent Transportation Systems (ITS), IEEE, <http://standards.ieee.org/findstds/standard/1609.11-2010.html>
- IEEE 1609.12-2016 - IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Identifier Allocations, IEEE, [https://standards.ieee.org/standard/1609\\_12-2016.html](https://standards.ieee.org/standard/1609_12-2016.html)
- IEEE 802.11-2016 – IEEE Standard for Information technology – Telecommunications and information exchange between systems. Local and metropolitan area networks – Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE, [https://standards.ieee.org/standard/802\\_11-2016.html](https://standards.ieee.org/standard/802_11-2016.html)

## SAE (Society of Automotive Engineers)

- SAE J2735\_202007 – V2X Communications Message Set Dictionary, SAE, [https://www.sae.org/standards/content/j2735\\_202007/](https://www.sae.org/standards/content/j2735_202007/)
- SAE J2945\_201712 – Dedicated Short Range Communications (DSRC) Systems Engineering Process Guidance for SAE J2945/X Documents and Common Design Concepts, SAE, [https://www.sae.org/standards/content/j2945\\_201712/](https://www.sae.org/standards/content/j2945_201712/)
- SAE J2945/6 (WIP) – Performance Requirements for Cooperative Adaptive Cruise Control and Platooning, SAE, <https://www.sae.org/standards/content/j2945/6/>
- SAE J2945/8 (WIP) – Cooperative Perception System, SAE, <https://www.sae.org/standards/content/j2945/8/>
- SAE J2945/9\_201703 – Vulnerable Road User Safety Message Minimum Performance Requirements, SAE, [https://www.sae.org/standards/content/j2945/9\\_201703/](https://www.sae.org/standards/content/j2945/9_201703/)
- SAE J3067\_201708 – Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary [SAE J2735] Using Systems Engineering Methods, SAE, [https://www.sae.org/standards/content/j3067\\_201408/](https://www.sae.org/standards/content/j3067_201408/)
- SAE J3161 (WIP) – On-Board System Requirements for LTE V2X V2V Safety Communications, SAE, <https://www.sae.org/standards/content/j3161/>



### 3. How to Access CV Applications shown in the Table

V2I Safety	Environment	Mobility
<p>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)</p>	<p>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</p>	<p>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</p>
V2V Safety	Road Weather	Smart Roadside
<p>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)</p>	<p>Motorist Advisories and Warnings (MAW) Enhanced MDSS Vehicle Data Translator (VDT) Weather Response Traffic Information (WxTINFO)</p>	<p>Wireless Inspection Smart Truck Parking</p>
Agency Data		
<p>Probe-based Pavement Maintenance Probe-enabled Traffic Monitoring Vehicle Classification-based Traffic Studies CV-enabled Turning Movement &amp; Intersection Analysis CV-enabled Origin-Destination Studies Work Zone Traveler Information</p>		

CV applications detailed descriptions and supporting documentation can be accessed by clicking on the blue category tabs of the table shown above to the USDOT website:  
[https://www.its.dot.gov/pilots/cv\\_pilot\\_apps.htm](https://www.its.dot.gov/pilots/cv_pilot_apps.htm)

The following applications Supporting Documentation can be accessed by clicking on each link shown below.

- Red Light Violation Warning (**RLVW**)
  - An application that broadcasts signal phase and timing (SPaT) and other data to the in-vehicle device, allowing warnings for impending red-light violations.
- Curve Speed Warning (**CSW**)
  - An application where alerts are provided to the driver who is approaching a curve at a speed that may be too high for safe travel through that curve.
- Stop Sign Gap Assist (**SSGA**)
  - An application that utilizes traffic information broadcasting from roadside equipment to warn drivers of potential collisions at stop sign intersections.
- Spot Weather Impact Warning (**SWIW**)
  - An application that warns drivers of local hazardous weather conditions by relaying management center and other weather data to roadside equipment, which then re-broadcasts to nearby vehicles.
- Reduced Speed/Work Zone Warning (**RSWZ**)
  - An application that utilizes roadside equipment to broadcast alerts to drivers warning them to reduce speed, change lanes, or come to a stop within work zones.
- Pedestrian in Signalized Crosswalk Warning (Transit)
  - An application that warns transit bus operators when pedestrians, within the crosswalk of a signalized intersection, are in the intended path of the bus.



**Supporting Documentation Links**

**RLVW, CSW, and SSGA**

- [Accelerated Vehicle-to-Infrastructure \(V2I\) Safety Applications Concept of Operations Document](#)
- [Accelerated Vehicle-to-Infrastructure \(V2I\) Safety Applications System Requirements Document](#)

**SWIW and RSWZ**

- [Vehicle-to-Infrastructure \(V2I\) Safety Applications Concept of Operations Document](#)
- [Vehicle-to-Infrastructure \(V2I\) Safety Applications System Requirements Document](#)

**Pedestrian in Signalized Crosswalk Warning (Transit)**

- [Transit Safety Retrofit Package Development TRP Concept of Operations](#)
- [Transit Safety Retrofit Package \(TRP\) Applications Requirements](#)
- [Transit Safety Retrofit Package \(TRP\) Architecture and Design Specifications](#)

**4. Glossary**

Term	Definition
Application	A piece of software that processes inputs for a specific use or purpose.
Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)	A USDOT-developed common framework for planning, defining, and integrating intelligent transportation systems. It 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.).
Backhaul	The closed network communications links between a Traffic Management Center (or other back offices), links between TMCs, and field installations (such as traffic signal controllers, traffic cameras, and other sensors). This could also include the link between the Security Credential Management System (SCMS) and roadside distribution device.
Basic Safety Message (BSM)	The message containing the core data set transmitted by the connected vehicle for safety-related purposes (vehicle size, position, speed, heading acceleration, brake system status). The message includes an optional extension that can report additional data depending upon events (e.g., anti-lock brakes activated) but the availability of types of extension data varies by vehicle model. 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 or receive messages from another device. Within the scope of V2X, we specifically mean those connected devices that are a part of an ITS trust domain, thereby allowing them to transmit and receive messages with other ITS-trusted connected devices. Within the scope of this course (V2V and V2P), we specifically mean those connected devices that are a part of the ITS trust domain established by the SCMS, thereby allowing them to transmit and receive messages with SCMS-trusted connected devices A connected device can be sub-categorized as an OBU or RSU.
Connected Vehicle	A vehicle containing an OBU or Aftermarket Safety Device (ASD).



Term	Definition
Dedicated Short Range Communications (DSRC)	The use of non-voice radio techniques to transfer data over short distances between roadside and mobile radio units, between mobile units, and between portable and mobile units to perform operations related to the improvement of traffic flow, traffic safety and other intelligent transportation service applications in a variety of public and commercial environments. . [FCC, Dedicated Short Range Communications of Intelligent Transportation Services – Final Rule, FR Doc No: 99-30591]. A technology for the transmission of information between multiple vehicles (V2V) and between vehicles and the transportation infrastructure (V2I) using wireless technologies.
Interoperability	Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged. [ISO 24765:2017]
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.
On-Board 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 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.
On-Board 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.
RSE	Roadside Equipment (RSE), a 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 such functions as data security, encryption, buffering, and message processing. It may also be referred to as the roadside ITS station.
RSU	NTCIP 1218 standard defines RSU as: a field device that supports secure communications with connected devices, and devices and may include a computing platform running applications. The RSU exchanges data among nearby connected devices (vehicles or mobile devices), other ITS Roadside Devices, and management systems at centers (such as a Traffic Management Center (TMC) or a Connected Vehicle Back Office System). In this context, the RSU is a NTCIP device. FCC defines RSU as a DSRC transceiver that is mounted along a road or pedestrian passageway. An RSU may also be mounted on a vehicle or is hand carried, but it may only operate when the vehicle or hand carried unit is stationary. Furthermore, an RSU operating under this part is restricted to the location where it is licensed to operate. However, portable or hand-held RSUs are permitted to operate where they do not interfere with a site licensed operation. An RSU broadcasts data to OBUs [On-Board Units] or exchanges data with OBUs in its communications zone. An RSU also provides channel assignments and operating instructions to OBUs in its communications zone, when required.



Term	Definition
Security Certificate Management System (SCMS)	A public key infrastructure (PKI) approach to security involving the management of digital certificates that are used to sign and authenticate messages that are exchanged among connected devices that might have no direct relationship with each other.
Signal Phase and Timing (SPaT)	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.
V2I-Vehicle to Infrastructure	The exchange of information between a vehicle and a roadside device or centralized equipment to enhance safety, mobility, and sustainability.
Vehicle-to-Everything (V2X)	The exchange of information between a vehicle one or more connected devices to enhance safety, mobility, and sustainability. The other connected device might be another vehicle, a pedestrian or other vulnerable road user device, a roadside station, or a central system.
Vehicle-to-Pedestrian (V2P)	The exchange of information between a vehicle and a connected device representing a pedestrian or other vulnerable road user to enhance safety, mobility, and sustainability.
Vehicle-to-Vehicle (V2V)	The exchange of information between vehicles to enhance safety, mobility, and sustainability.
WAVE Short Message Protocol (WSMP)	A low-overhead TransNet Layer protocol designed for use over DSRC. Common protocol designed for both network and transport layers with minimal overheads for direct broadcast communication.
WAVE- Wireless Access in Vehicular Environments	A radio communications system intended to provide seamless, interoperable services to transportation users. Term is associated with IEEE 1609 family of standards.

## 5. Acronyms

Acronym	Description
3GPP	3rd Generation Partnership Project
5G	5 <sup>th</sup> Generation (cellular technology)
BSM	Basic Safety Message
C-ITS	Cooperative ITS
CV	Connected Vehicle
C-V2X	Cellular Vehicle-to-Anything
DSRC	Dedicated Short Range Communications
FCC	Federal Communications Commission
GNSS	Global Navigation Satellite System (A generic name for GPS)
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Standards Organization
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LTE	Long-Term Evolution (cellular technology)
OBE	Onboard Equipment (OBU-Onboard Unit)
OBU	Onboard Unit
RSE	Roadside Equipment
RSU	Roadside Unit
RSZW	Reduced Speed Zone Warning SAE
SAE	Society of Automotive Engineers
SCMS	Security Credential Management System





Acronym	Description
SDO	Standards Development Organization
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
WAVE	Wireless Access in Vehicular Environments
WIP	Work in Progress
WSMP	WAVE Short Message Protocol

## 6. References

1. An Overview of USDOT Connected Vehicle Roadside Unit Research Activities-2017  
<https://rosap.ntl.bts.gov/view/dot/34763>
2. V2I Resources, USDOT, <https://www.its.dot.gov/v2i/>
3. V2I Message Lexicon, USDOT, 2016 <https://rosap.ntl.bts.gov/view/dot/32033>
4. Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements Document <https://rosap.ntl.bts.gov/view/dot/26499>
5. AASHTO Connected Vehicle Infrastructure Deployment Analysis
6. USDOT ITS Strategic Research Plan, 2020-2025. <https://its.dot.gov/stratplan2020/index.htm>
7. Preparing Local Agencies for the Future of Connected and Autonomous Vehicles, 2019, Iowa State University, [www.dot.state.mn.us](http://www.dot.state.mn.us)
8. USDOT DSRC Roadside Unit (RSU) Specifications Document, Version 4.0, April 15, 2014.  
<https://rosap.ntl.bts.gov/view/dot/3600>
9. USDOT Vehicle Awareness Device Specification, Version 3.6, January 25, 2012.
10. USDOT "5.9GHz DSRC Aftermarket Safety" Device Specification, Version 3.0, 2011.
11. Connected Vehicle Applications, USDOT. [https://www.its.dot.gov/pilots/cv\\_pilot\\_apps.htm](https://www.its.dot.gov/pilots/cv_pilot_apps.htm)
12. Security Credential Management System (SCMS):  
<https://www.its.dot.gov/resources/scms.htm>
13. Connected Vehicle Modules: CV 261, CV 262:  
[https://www.pcb.its.dot.gov/stds\\_modules.aspx](https://www.pcb.its.dot.gov/stds_modules.aspx)



## 7. Study Questions

1. **Which of the following is NOT always a part of V2X communication services?**
  - a) Onboard Unit (OBU).
  - b) Roadside Unit (RSU).
  - c) Roadside Equipment (RSE).
  - d) Center to a Field (C2F) Communication.
  
2. **Which of the following is NOT a V2I application?**
  - a) Curve Speed Warning (CSW)
  - b) Transit Signal Priority (TSP)
  - c) Forward Collision Warning (FCW)
  - d) Railroad Crossing Violation Warning (RCVW)
  
3. **Which of the following standards is NOT directly related to DSRC V2I communication, but can be used?**
  - a) IEEE 1609 family (WAVE)
  - b) SAE J2735 data dictionary
  - c) NTCIP 1203 v3.0 (ASC)
  - d) IEEE 802.11
  
4. **Which of the following is NOT a technical challenge?**
  - a) Conformance to standards.
  - b) Certification and interoperability testing of devices.
  - c) Over the air Firmware (software) upgrades for devices.
  - d) Data Ownership.
  
5. **Which of the following is NOT a true statement?**
  - a) Testing has shown that Interoperability is achievable.
  - b) V2I applications such as TSP are successfully deployed.
  - c) DSRC is a reliable communication medium.
  - d) Performance testing is completed during CV Pilots.



## 8. Icon Guide

The following icons are used throughout the module to visually indicate the corresponding learning concept listed out below, and/or to highlight a specific point in the training material.

- 1) **Background information:** General knowledge that is available elsewhere and is outside the module being presented. This will be used primarily in the beginning of slide set when reviewing information readers are expected to already know.



- 2) **Tools/Applications:** An industry-specific item a person would use to accomplish a specific task and applying that tool to fit your need.



- 3) **Remember:** Used when referencing something already discussed in the module that is necessary to recount.



- 4) **Refer to Student Supplement:** Items or information that are further explained/detailed in the Student Supplement.



- 5) **Example:** Can be real-world (case study), hypothetical, a sample of a table, etc.



- 6) **Checklist:** Use to indicate a process that is being laid out sequentially.

