V2I Hub

Deployment Guide

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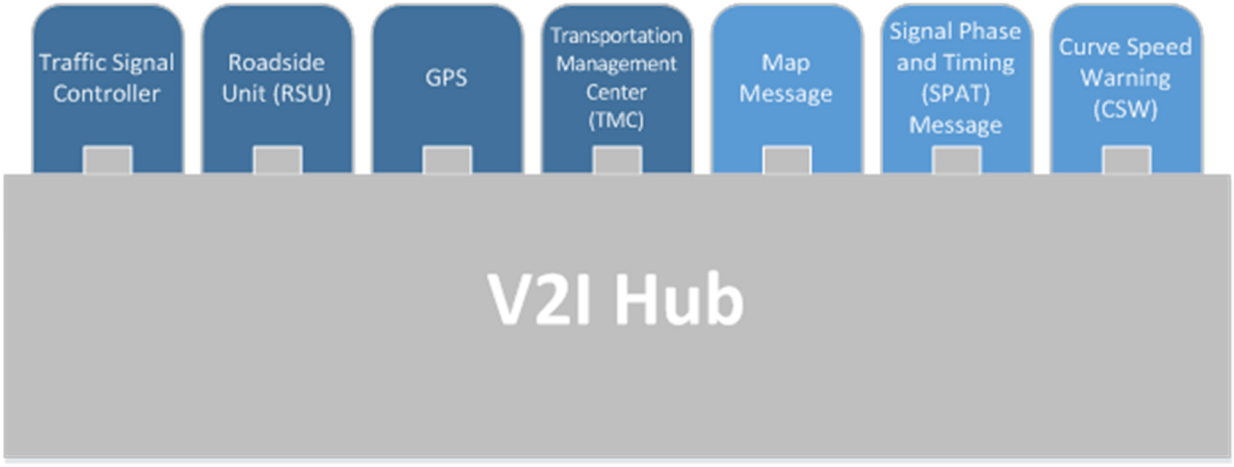

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16. Abstract

Connected Vehicle technologies help reduce the number of driving related injuries and fatalities by allowing road users to be aware of potential dangerous situations on the road. There are two main types of Connected Vehicles communications, vehicle-to-infrastructure and vehicle-to-vehicle. Vehicle-to-infrastructure communication takes place between vehicles and deployed roadside communication devices, which capture vehicle generated data while providing information pertaining to safety, mobility, and environmental conditions.

This guide provides a detailed approach for deploying the V2I Hub vehicle to infrastructure solution at a signalized intersection. It walks through each phase of the deployment step-by-step to ensure a successful implementation. Traffic engineers responsible for performing the deployment are the intended audience for this document.

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Executive Summary

Connected Vehicle (CV) software development and deployments of CV technology have been a major focus of the U.S. DOT's research over the past decade. As the Federal Government encourages state and local entities to deploy CV technology under their jurisdiction, the V2I Hub Deployment Guide was created to provide an outline with step-by-step instructions for deploying the V2I Hub software and hardware. This deployment guide outlines a phased approach and provides insight into needs analysis, planning, design, procurement, field deployment, and post deployment. This document is a part of the V2I Hub series of documents produced by the V2I Reference Implementation project. The rest of the documents are listed below. It is suggested to start with reviewing the V2I Hub Guidebook.

- V2I Hub Guidebook
- V2I Hub Plugin Programming Guide
- V2I Hub Plugins
- V2I Hub Administration Portal User Guide
- V2I Hub Software Configuration Guide.

Chapter 1. Background

The V2I Hub is part of U.S. DOT's V2I Program, developed to support jurisdictions deploying Vehicle-to-Infrastructure (V2I) technology by reducing integration issues and enabling use of their existing transportation management hardware and systems. The V2I Hub is a Connected Vehicle (CV) software platform developed to be deployed at signalized intersections, and other infrastructure locations with the intention of making roadways safer and smarter by reducing accidents and providing informational alerts to drivers.

The V2I Hub software can be found in the U.S. DOT's Open Source Application Development Portal (OSADP) repository along with supporting documentation and other reference materials at https://www.itsforge.net

This deployment guide was created for parties deploying the V2I Hub to do so successfully. It is recommended that an engineer or individual with an Intelligent Transportation Systems (ITS) or CV background help lead the deployment. This guide describes the roadmap through the pre-deployment and post-deployment process and is provided as a V2I Hub specific supplement to existing agency procedures.

Chapter 2. Needs Analysis

The V2I Hub Guidebook provides a high-level outline of what is required to deploy the V2I Hub.[1] It describes the necessary hardware components and lists the technical specifications required for the V2I Hub. The V2I Hub software is also explained and broken down into the plugins and core.

Prior to deploying the V2I Hub, a needs analysis should be conducted to address the deploying agency's requirements. The questions below should be addressed, while conducting the needs analysis. Sample responses are provided to represent use-cases.

- What is the objective for this V2I Hub deployment?
    - e.g., To enable V2I communication at a signalized intersection, to improve pedestrian safety, to improve safety at rail crossings.
- What functionality is desired or needed?
    - e.g., Broadcast MAP and SPaT messages to CVs approaching a signalized intersection, enable transit vehicle operators with pedestrian detection alerts and warnings when traversing the intersection, enable vehicles that approach rail crossings with violation warnings and alerts.
- What are the trade-offs or impact of implementing additional functionality with regards to the V2I applications?
    - How does this impact the cost of deployment?
        - e.g., Availability and placement of surrounding infrastructure will impact the cost of any additional hardware required, pedestrian detection technology will require additional hardware, software, and contractor installation costs, vehicles will require additional hardware, software, and coordination with the authorizing rail entity.
    - How does this impact the schedule for deployment?
        - e.g., Establishing a Memorandum of Understanding (MOU) or contract with local stakeholders impacted by the deployment could delay installation, researching and or evaluating pedestrian detection technology would be required prior to the installation, coordination and testing with the rail entity would be required prior to field deployment.
    - What are the risks or challenges associated with adding functionality?
        - e.g., Introducing new hardware and software could require more time or effort during installation and integration, additional coordination efforts with authorizing entities.
- Would the additional functionality meet the deploying agency's objectives?
    - e.g., Yes, after all considerations, deploying the application meets the agency's needs and is an accepted solution.

After all considerations have been addressed and resolved, the deployment of the V2I Hub may proceed to the planning phase. Planning is one of the most crucial phases and should be the first phase during deployment. In this phase, the site of deployment should be identified, the appropriate licenses and permits shall be applied for, coordination with stakeholder agencies must take place, site specific details should be assessed, and a final decision should be made on the application(s) being deployed. Table 2 in Chapter 3 describes a list of example considerations to be addressed. While all the items mentioned

above are crucial, it is essential for all stakeholder buy-in and for site specific details to be comprehended. Stakeholder engagement is the critical path for a successful deployment.

The next phase of deployment is the design phase. Deployment design should be occurring simultaneously during the planning phase. The system architecture shall be developed to understand how the system is going to work and how it will be constructed. An example V2I Hub system architecture is shown in the *V2I Hub Guidebook* titled 'Figure 3. V2I Block Diagram'. The architecture illustrates the physical interfaces, which will be an important step leading up to equipment selection. The architecture developed should be consistent with the National ITS architecture to the extent practicable.

Once the equipment has been selected, the procurement phase may begin. Depending on the agency deploying the V2I Hub, there may be several procurement options available. Procurement is discussed further in Chapter 5.

After all hardware has been procured, the field deployment phase can be kicked-off. Deployment includes the physical installation of the V2I Hub hardware, integration of all hardware components and software, and testing to ensure the hardware and software are working as designed.

It is now time to implement the post deployment plan conceived in the planning phase after a successful installation. This plan addresses the day-to-day operations of the deployment, how the V2I Hub is going to be monitored, and a strategy for any scheduled or unscheduled maintenance and repair.

Table 1 presents a sample schedule identifying key tasks throughout the different phases of deployment. This schedule is not representative for every deployment as the scope and challenges encountered may vary. This schedule is meant to demonstrate interdependencies and describe the general order of operations of deployment. Based off previous deployments, the physical installation is typically the shortest task of the deployment itself, while the licensing and stakeholder coordination tasks have proven to be lengthy and time-consuming processes.

Table 1. Gantt Chart Sample Schedule

Deployment Schedule	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Phase 1: Needs Analysis												
Project Initiation												
Phase 2: Planning												
Planning Considerations												
V2I Hub Applications												
Stakeholder Coordination												
Licensing												
Permits												
Phase 3: Design												
Architecture												
Interfaces												
Equipment Selection												
Phase 4: Procurement												
Purchase Equipment												
Phase 5: Field Deployment												
Physical Deployment												
Integration												

Deployment Schedule	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Testing												
Phase 6: Post Deployment												
Operations												
Monitoring												
Maintenance												

The following chapter addresses the planning phase in detail.

Chapter 3. Site Planning

Planning Considerations

The V2I Hub is a software platform that resides in hardware to provide infrastructure connectivity in support of V2I applications. Although it can be installed in standalone computing hardware, traffic signal controllers, and RSUs, this guide assumes a standalone computing hardware approach as, among other benefits, it is equipment agnostic. The remainder of this chapter focuses on site planning where the V2I Hub and the hardware components that it serves will reside. Determining the site where the V2I Hub shall be deployed should be the first step in the planning phase. The deployment location will affect the V2I Hub applications that can be implemented, stakeholders, licensing, and permits. The planning phase is detailed below in chronological order:

1. Physical site selection
2. V2I Hub applications
3. Stakeholder coordination
4. Licensing
5. Permits.

Site selection should occur based on the deployment objective. Depending on the application(s) being deployed, some sites may be better suited for deployment than others. For example, the V2I Hub can be deployed to support safety applications at signalized and non-signalized intersections (vehicle and pedestrian protection), rail crossings (vehicle-train collision applications), transit shelters (transit pedestrian and vehicle protection), curved roadways, highways, and many more. It is recommended that multiple site locations are considered and site surveys are conducted prior to making a final decision. Site surveys are a crucial step in understanding the site-specific details. Multiple site surveys may be necessary with the different stakeholders or for acquiring additional information related to that site. With the V2I Hub applications currently available in the U.S. DOT's OSADP repository, the V2I is optimized to be installed at a signalized intersection. A site survey at a signalized intersection may include the following:

- Driving through the intersection of interest from different directions.
- Walking the corners and crosswalks from different directions.
- Walking stakeholders through the intersection and explaining the deployment plan.
- Measuring and estimating
    - pole heights and outer diameters, pole composition
    - crosswalk lengths and widths
    - lane lengths and widths.
- Documenting the surrounding infrastructure for future reference by taking photographs and drawing a sketch.
- Identifying the location and height where the RSU will be installed. It is recommended this is done prior to installation for FCC licensing purposes.

- Viewing inside the traffic cabinet to assess existing hardware such as the make and model of the traffic controller and Ethernet Switch port availability. Hardware installation considerations should include inspecting available conduit space, taking measurements of available space for deployment equipment, estimating cable lengths, and verifying the number of power outlets available.
- Determining any supplemental hardware that will be needed such as Power over Ethernet (PoE) extenders/repeaters, additional poles, pole bases, pole extenders, mast arms, mounting brackets, etc.
- Identifying peak traffic hours to avoid during deployment.
- Conceptualizing where hardware external to the traffic cabinet would be installed and cabling would be run.
- Identifying/confirming the type of power and availability of using power inside the traffic cabinet.
- Identifying stakeholders who may be affected by the deployment.
- Consulting with the city traffic managers on the IP address schema used by the existing equipment in the cabinet.
- Consulting with the traffic engineer or technician to confirm the traffic signal controller is configured to enable SPaT transmission. Refer to the SPaT Plugin Configuration section of the *V2I Hub Software Configuration Guide* for SPaT for additional information.

After surveying the site(s), it is likely that key infrastructure, feasibility, or technical challenges will be observed. The impact on functionality stemming from these unique challenges must be carefully considered as decision criteria for moving forward with the site.

Table 2 lists a few potential challenges that may be encountered upon a site survey.

Table 2. Planning Considerations

Consideration Type	Description of Consideration	Impact of Consideration
Infrastructure	Limited or lack of infrastructure	Additional deployment costs to install new poles, pole bases, mast arms, conduit, span wire
	Lack of power available	A new power line may need to be run, or a power line may need to be tapped to provide power to the site location
Feasibility	Affiliated agencies necessary to coordinate for deployment may be unwilling to agree to terms and conditions	A new site may be required
	Underground conduit is filled	New conduit may need to be run, or another location must be chosen
Technical	Intersection of interest is located in an urban canyon setting	Poor GPS reception could affect the functionality of the application(s)
	A nearby bridge inhibits transmission strength	Vehicles using the application may only receive messages from a limited distance

Consideration Type	Description of Consideration	Impact of Consideration
Security	Local security	Deployed V2I Hub should be secured in a locked traffic signal controller cabinet.
	Network security	Deployed V2I Hub connected to a network should follow network security rules for the deploying agency.
	Security Credential Management System (SCMS)	Security certificates for the DSRC RSU need to be obtained and installed on the RSU following the RSU manufacturer instructions.

V2I Hub Applications

As mentioned above in 'Planning Considerations', the CV on-board applications are dependent on the site selected for deployment. A couple of example scenarios are described below:

- Example Scenario 1: The deploying agency wishes to implement Curve Speed Warning (CSW) application to warn drivers when they must reduce speed around a curved roadway. This would require the V2I Hub to be installed near the curve side and for the designated vehicles to be outfitted with an on-board radio.
- Example Scenario 2: The deploying agency wishes to implement the Enhanced Pedestrian in Crosswalk Warning (E-PCW) application to improve pedestrian safety. The V2I Hub must be installed at a signalized intersection in addition to the extra hardware and software required for supporting the pedestrian detection technology.

Multiple V2I plugins can be run on the V2I Hub simultaneously creating data to support an array of CV applications. Some CV applications that the V2I Hub creates data to support are listed in Table 3.[2] In addition to the applications already supported by the V2I Hub, if the deploying agency wishes to create their own application or implement an application not currently supported, refer to the *V2I Hub Plugin Programming Guide*. The V2I Hub is application software agnostic and can support all other CV applications.

Table 3. V2I Hub CV OBU Supported Applications

Application Type	V2I Plugin	OBU CV Application
Mobility	• Multi-Modal Intelligent Traffic Signal Systems (MMITSS)	• Intelligent Traffic Signal System • Transit Signal Priority • Pedestrian Mobility • Freight Signal Priority • Emergency Vehicle Priority
Transit/Pedestrian Safety	• SPaT • MAP • Pedestrian Detection	• Enhanced Pedestrian in Crosswalk Warning (E-PCW) • Transit Stop Pedestrian Warning (TSPW)
V2I Safety	• SPaT • MAP	• Red-Light Violation Warning (RLVW)
V2I Safety	• Rail Crossing Violation Warning (RCVW) Roadside	• RCVW In-Vehicle
V2I Safety	• Curve Speed Warning (CSW)	• CSW
Road Weather	• Intelligent Network Flow Optimization (INFLO)	• Weather-Responsive Traffic Management • Motorist Advisories and Warnings

Many of the V2I Hub plugins listed above have been developed during the IVP or V2I Reference Implementation projects and can be obtained with the V2I Hub source code from the U.S. DOT's OSADP repository. For a additional information on each of the V2I Hub plugins, refer to the *V2I Hub Plugins document*. The RCVW Roadside plugin and in-vehicle application, along with the *V2I Hub Plugins document* can also be found in the U.S. DOT's OSADP repository. The Pedestrian Detection plugin is the only plugin not available in the U.S. DOT's OSADP repository and will need to be developed or supplied by a third party.

Stakeholder Coordination

After the location and applications have been finalized, review the conceptual design conceived during the site survey as well as the stakeholders identified. Stakeholders include anyone that may be affected by the deployment. Table 4 lists types stakeholders and describes the potential impact of the deployment.

Table 4. Identified Stakeholders

Stakeholder Types	Stakeholder Involvement	Deployment Impact on Stakeholders
Municipality	Authority over the City, owner of infrastructure installed throughout the City	The City will give initial authority for the deployment and will be responsible for approving the permits required. The City may also have means of performing the installation.
Regional or State DOT	Ownership of State Infrastructure	State gives authority for deployment and responsibility of permits required for installation on state owned infrastructure.
Utility Owners	Power providers and City infrastructure owners	The power or light utility owners will be responsible for giving authority for installing on their equipment in the field if needed or for running power to a desired location.
Third-Party Contractor(s)	Installation of hardware, aid in maintenance of deployment	A third-party contractor may be contracted for installing the hardware at the intersection and provide maintenance if needed. The contractor should have the means and capabilities of performing the installation and are also capable of procuring the hardware.
Traffic Management Center	Can receive real-time data from the deployment to monitor traffic data	Support for integration with TMC network and other resources (e.g. Operational Data Environment)
Partner(s)	Varying on the application, the deploying agency may partner with another entity.	Coordination and support will be necessary if you have a partner throughout the deployment process.
Federal Communications Commission (FCC)	Authority of broadcasting radio frequency messages	The FCC must give the deploying agency authority to broadcast radio messages from the RSU.

The stakeholders involved in the deployment process are based on the deployment location and requirements for the system. Also, if the municipality owns the surrounding infrastructure at the site of deployment, it is unlikely to have to coordinate with any utility owners.

It should be recognized that the magnitude and complexity of the V2I Hub system being deployed can greatly affect the coordination effort between stakeholders. The number of stakeholders involved as well as the level of their involvement shall also be acknowledged. For example, if the deploying agency has a partner in the deployment, regular coordination shall be expected from the beginning through the end. If an electrical contractor is performing the installation, it may require a fraction of the coordination a partner requires because they may only be involved in the project closer to the deployment phase.

Depending on the site, the third-party performing the installation could vary based on geographical authority. The City may perform the installation or an electrical contractor or ITS deployment agency may be contracted to support the installation.

The third-party performing the installation should have the following responsibilities and capabilities:

- Participate in on-site walkthrough with deploying agency.
- Coordination amongst applicable utility companies
    - Identifying underground and above-ground utilities that could be impacted by installation such as: gas, electric, water, steam, and sewer.
- Review deploying agency's design for potential impacts during installation.
- Filing and obtaining necessary permits for installation.
- Part procurement and storage (optional).
- Determining the pole type to support deployment hardware in compliance with City Standards, Code and Regulations as needed.
- Authority to open and work within the City's traffic cabinet.
- Ability to manage traffic flow during construction.
- Transporting, installing, and mounting poles, pole bases, and mast arms.
- Ability to install span wire.
- Ability to tree trim, cut cement, design and pour foundations.
- Pulling power and signal cables through conduit
    - Ability to field terminate Ethernet cabling.
- Supply machinery, tools, bucket trucks, signage, cones, mounting hardware accessories.
- Confirming and obtaining power inside the traffic cabinet.

Once the list of stakeholders has been finalized, agreements with stakeholders need to be created and documented. Depending on the agreement, it may be necessary for the deploying agency to seek guidance from their legal team on drawing up or finalizing agreements consistent with internal policies or procedures. For example, a Memorandum of Understanding may need to be put in place with a City municipality. On the other hand, a Statement of Work may have to be written and agreed upon followed by a contract for setting up terms and conditions with a third-party contractor.

Licensing

The Dedicated Short-Range Communication (DSRC) radio Roadside Unit (RSU) is the primary means of achieving V2I communication as part of the V2I Hub system. The RSU is responsible for transmitting and receiving DSRC messages at the intersection. RSUs operate in the 5.9GHz frequency range, which requires an FCC license to broadcast, as mentioned in the V2I Hub Guidebook.

The deploying agency must apply for an Intelligent Transportation Service (Non-Public Safety) license to deploy a broadcasting radio. The application requires all deployment locations to be registered as well as an operating radius, which is limited to the broadcast range of the DSRC radio. The license is only required for an installation of the radio at a fixed location such as an intersection. Any vehicles with installed radios are covered under the license if they operate within the broadcast range of the radio. The roadside transmitting device must be deployed within one year of receiving the license and is valid for up to ten years.

Apply for the FCC license here: FCC License Application (http://www.fcc.gov/help/applying-new-license-universal-licensing-system-uls).

Permits

The authorizing municipality, complexity, and level of involvement required for the installation will determine the types of permits required. An experienced local contractor may have insight on the types of permits required; however, if an electrical contractor is not performing the installation, the deploying agency should contact the authorizing municipality seeking advisement on the permits to apply for. The time required for receiving approval is completely dependent upon each municipality.

Chapter 4. Design

The V2I Hub system architecture and design is heavily dependent on the application(s) being deployed as well as the physical deployment site. These two variables will determine the types of interfaces and the equipment that will be selected for deployment. The architecture, interfaces, and selection of equipment for the example V2I Hub system shown in Figure 3 of the V2I Hub Guidebook is discussed in the proceeding subsections.[1]

The V2I Hub system architecture and design ultimately determines the hardware that shall be procured for deployment. The V2I Hub Guidebook provides an example of a V2I Hub system architecture and identifies technical specifications or standard communication protocols the software must follow.

Architecture

The V2I Hub system architecture described in the V2I Hub Guidebook is illustrated below in Figure 1.[1] This block diagram identifies the generic functional hardware components required for deployment and shows the interconnectivity of the V2I Hub system integrated with a signalized intersection. It should be noted that depending on the location where the V2I Hub is being deployed, modifications to the hardware architecture may be required based on physical characteristics of the intersection geometry or hardware previously installed in the traffic cabinet.

Possible considerations to the V2I Hub system architecture may include:

- The IP address scheme for the V2I Hub and the RSU will need to be configured in accordance with the IP address scheme set forth for the existing components in the traffic cabinet. Refer to the V2I Hub Network Configuration for Ubuntu section of the *V2I Hub Software Configuration Guide* for how to configure the IP address of the V2I Hub. Refer to the manufacturer documentation for how to configure the RSU's IP address.
- More than one RSU may be required depending on the size and geometry.
- The hose clamps typically provided with the RSU, or to be used with the RSU mounting kit, may not be the appropriate length or width for the installation. The diameter of the pole or mast arm will determine the required length of the hose clamps or band straps required. Verify the width of the slot in the RSU mount is wide enough for the length of strap required prior to installation.
- PoE extenders/repeaters may be required to power the RSU if the length of the Ethernet cable extends past 300m
    - Some PoE extenders/repeaters have built in surge protection, which would allow the surge protector shown in Figure 1 to be removed.
- The Ethernet cable that makes a connection between the DSRC Radio and the surge protector (ETH 5) can be a pre-terminated if the distance between these components is known. However, it is recommended this cable be terminated after installation to allow for flexibility during installation.
- If multiple hardware components additional to the RSU require PoE inside the traffic cabinet, the Ethernet Switch shown in Figure 1 can be replaced with an Ethernet Switch that supports PoE. This will eliminate the need for PoE Injector shown in the figure.

- Some traffic cabinets may already have an Ethernet Switch installed and may lack the number of ports required by the V2I Hub. The Ethernet Switch required by the V2I Hub may be stacked with the existing switch or it can be replaced by a switch with the appropriate number of desired ports.

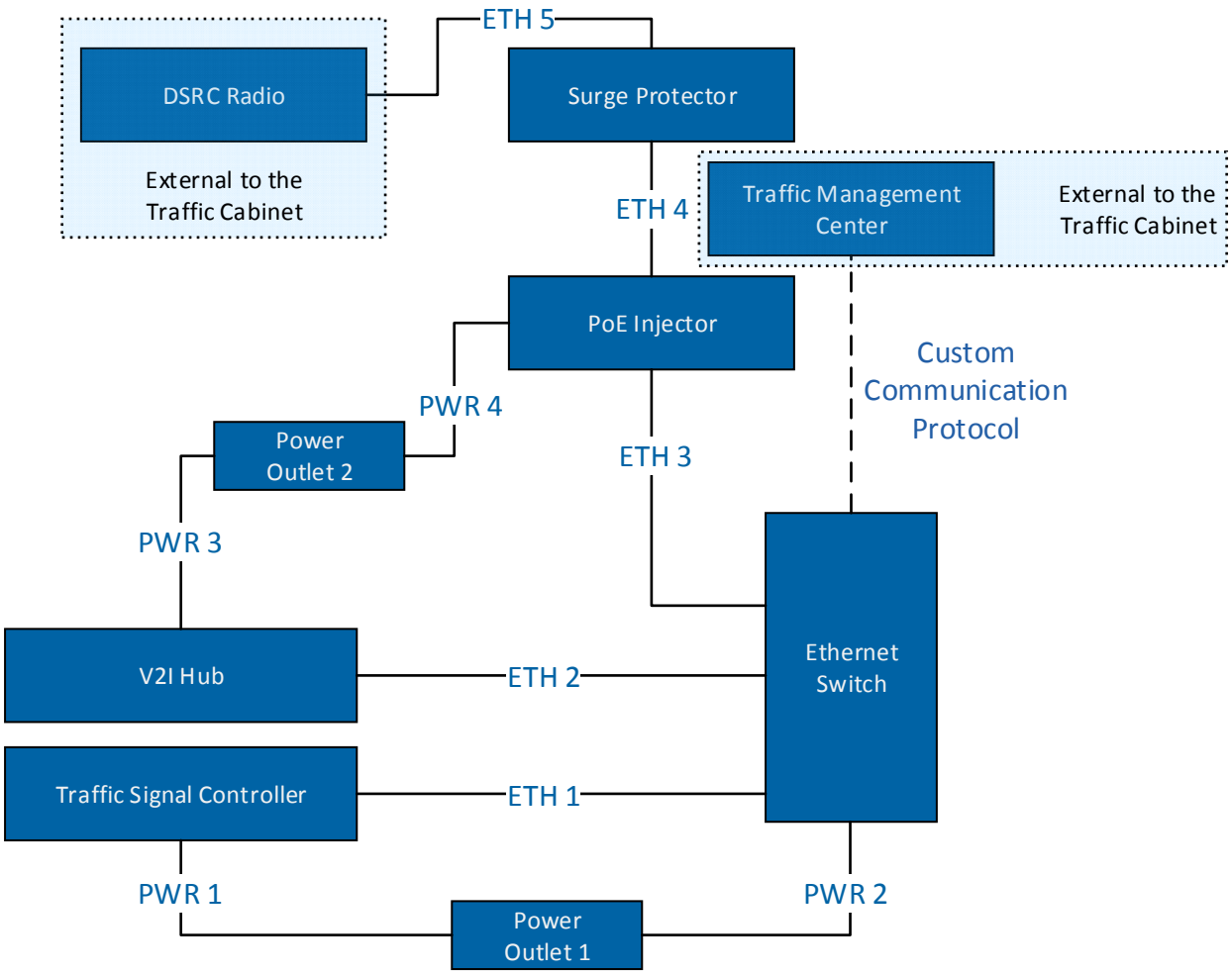

Figure 1. V2I Hub Block Diagram

Table 5, also displayed in the V2I Hub Guidebook, lists the hardware components shown in Figure 1 and describes their function relative to the system. It is recommended that all hardware components being deployed in the field be industrial grade with appropriate temperature ratings to withstand the extreme weather conditions.[1]

Table 5. Hardware Required for V2I Hub Deployment

Hardware Component	Hardware Function
Industrial Computer (V2I Hub)	• Hosts the V2I Hub software
Traffic Management Center	• Allows remote connectivity for monitoring, managing, and configuring the V2I Hub
RSU (Radio)	• Transmits and receives radio messages
GPS Antenna	• Transmits GPS location information
(2) Radio Antennas	• Transmits and receives radio messages
Traffic Signal Controller	• Provides SPaT information about the intersection
Ethernet Cable 5	• Connects the externally mounted RSU to the surge protector
Ethernet Cable 4	• Connects the surge protector and the PoE injector
Ethernet Cable 3	• Connects the PoE injector and the Ethernet switch
Ethernet Cable 2	• Connects the V2I Hub to the Ethernet switch
Ethernet Cable 1	• Connects the TSC to the Ethernet switch
Surge Protector	• Prevents electrical damage from lightning strikes
Ethernet Switch	• Allows multiple Ethernet connections to be made on one device on the same network
(3) Power Outlets	• Provide power for the hardware installed in the traffic cabinet

The specific interfaces for the hardware components listed above in Table 5 are described in the proceeding section.

Interfaces

For a successful deployment, it is critical to understand all the interfaces involved. Interfaces can be broken down into two types. Internal interfaces include all physical and logical interfaces in the system.[3] External interfaces are interfaces that exist between the system and the elements outside the system.[3] Table 6 lists the connections between the V2I Hub hardware components and describes the type of connection. Figure 2 illustrates the ‘Connection’ and ‘Physical Type’ columns listed in Table 6.

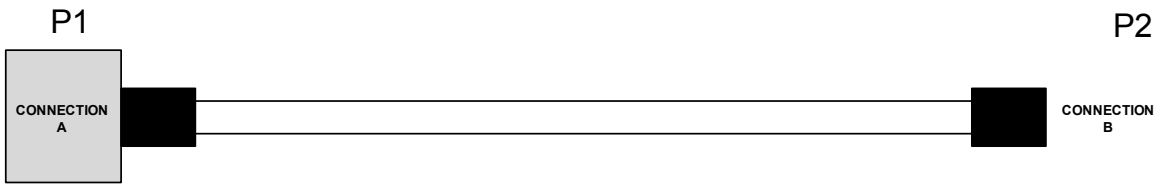

Figure 2. Cable Interface Diagram

The GPS and Radio Antennas listed in Table 6 connect directly to the DSRC Radio shown in Figure 1.

Table 6. V2I Hub Internal Interfaces

Hardware Component	Connection A	Physical Type 1	Connection B	Physical Type 2
GPS Antenna	Radio	N-Type	None	None
Radio Antenna 1	Radio	N-Type	None	None
Radio Antenna 2	Radio	N-Type	None	None
Ethernet Cable 1	Traffic Signal Controller	RJ-45 Plug	Ethernet Switch	RJ-45 Plug
Ethernet Cable 2	V2I Hub	RJ-45 Plug	Ethernet Switch	RJ-45 Plug
Ethernet Cable 3	PoE Injector	RJ-45 Plug	Ethernet Switch	RJ-45 Plug
Ethernet Cable 4	Surge Protector	RJ-45 Plug	PoE Injector	RJ-45 Plug
Ethernet Cable 5	Radio	RJ-45 Plug	Surge Protector	RJ-45 Plug
Power Cable 1	Traffic Signal Controller	*	Power Outlet 1	*
Power Cable 2	Ethernet Switch	*	Power Outlet 1	*
Power Cable 3	V2I Hub	*	Power Outlet 2	*
Power Cable 4	PoE Injector	*	Power Outlet 2	*

The asterisk in the Physical Type columns for all power cables represents the unknown type of connection. The type of power connection could vary depending on the make or model of the hardware component. Power Outlet 1 and 2 listed in Table 6 are arbitrary to represent multiple open outlets needed inside a traffic cabinet. The hardware components listed next to Power Outlet 1 and 2 do not represent a unique configuration to that power outlet.

Equipment Selection

After the system architecture has been finalized and all internal interfaces are understood, selecting the equipment with the required specifications is the next step. Equipment selection is the process of choosing the hardware components that will meet the needs of the deployment. Table 5 described the generic hardware components required and Table 6 explained the internal interfaces with respect to those hardware components. When selecting the equipment, there are many other considerations to be made.

- **External interfaces** – hardware mounting configurations, available space in the traffic cabinet, installation feasibility, cable length, pre-terminated or field terminated cables, converters.
- **V2I Hub Hardware specifications** – V2I Hub hardware specifications listed below in Table 7
- **RSU Hardware specifications** – The selected RSU must meet the RSU 4.1 specification. The transmission range of the RSU should be considered when selecting an RSU manufacturer. Adequate transmission range should be dictated by the requirements of the applications being deployed. Physical characteristics of the deployment site may impact RSU transmission range such as line of sight challenges and urban canyon environments.
- **Traffic Signal Controller specifications** – V2I Hub must communicate with a TS2 traffic signal controller providing the Traffic Signal Controller Broadcast Message over Ethernet.
- **Project requirements** – cost, temperature requirements, functional requirements, performance requirements.

Table 7 below lists the minimum V2I Hub hardware requirements derived from testing V2I Hub software. The table does not include all processor types or hardware specifications that can support the V2I Hub software.

Table 7. V2I Hub Hardware Specifications[1]

Hardware	Computer Processors	
	ARM Hardware Specifications	Intel Hardware Specifications
Processor	Freescale i.MX6 ARM Cortex A9 Quad Core 1GHz	Intel Core i3 processor Dual Core 1.7 GHz
Memory	1GB DDR3	4GB of RAM
Hard Drive Space	16GB SSD	16 GB SSD
Operating System	Ubuntu 16.04 LTS	Ubuntu 16.04 LTS

Chapter 5. Procurement

The hardware required for a V2I Hub deployment is defined above in Chapter 4. Although the hardware may be defined, the procurement process will likely be different for each deploying agency. Deploying agency policies and procedures may already define the procurement process, while others may not have to follow a defined approach. Below is a list of different approaches to the procurement process:

- **Competitive-bid** – the deploying agency may post the hardware requirements and technical specifications for third-party companies to bid on performing the procurement.
- **Pre-existing contract** – the deploying agency may have a pre-existing contract with a purchasing company or ITS entity who already performs the procurement.
- **Internal procurement office** – the deploying agency may have an internal purchasing department responsible for carrying out procurement.
- **Installation contractor** – if the deploying agency has contracted a third-party contractor to perform the installation, the contractor may also perform the procurement.

As the design is being finalized, it's advised that lead times for the different components are considered. The hardware components listed below are not standard commercially off the shelf (COTS) items that are regularly stocked and ready to ship. These products are typically made-to-order and are therefore subject to longer lead times, which may impact the deployment schedule.

- Poles
- Pole extenders
- Pole bases
- Mast arms
- RSU
- Computing Platform.

The entity performing the procurement shall have the following capabilities:

- **Lead time insight** – the procurement entity shall be able to provide the deploying agency with information regarding lead times.
- **Means of purchasing** – to simplify the purchasing process by eliminating additional transactions and paperwork, it is recommended the entity performing the procurement have adequate resources such as credit.
- **Identification of vendors** – the entity performing procurement shall be able to identify a supplier for each of the components.

Upon selecting a procurement process, consider the logistics between purchasing and installation including storage of purchased equipment. In addition to any long lead time items, it should be recognized that these items may need to be assembled, installed, or configured, which also impact schedule. Additional information regarding configuration of the system is detailed below in Chapter 6.

Chapter 6. Field Deployment

Once the hardware has been specified and procured, the hardware being deployed can be configured and provisioned prior to the field deployment. Configuring and testing the hardware will save a considerable amount of time during installation and should reveal any design or hardware challenges that would have previously been experienced in the field. Refer to the Pre-Deployment Hardware and Software Preparation checklist in the Appendix.

After the items on the Pre-Deployment Hardware and Software Preparation checklist have been addressed the field deployment process can be initiated. The field deployment process will vary for deploying agencies based on the amount of equipment being installed, the party performing the installation, and the testing required to verify the system. The physical deployment, integration, and testing phases of the installation are described in detail below. For all these phases of the deployment, it is recommended the party performing the installation be on-site for support.

Physical Deployment

Prior to the physical deployment, it will be necessary to have all permits in-hand and to coordinate logistics with all parties involved.

The installation may involve a combined effort on behalf of several parties.

- **Municipality** – may perform the installation or may wish to oversee the installation.
- **Third-party contractor** – may transport the hardware and perform the installation.
- **Deploying agency** – may perform the installation of hardware and may provide installation oversight among the other party supporting the installation.

Table 8 provides installation information regarding the hardware components identified in Table 5.

Table 8. Hardware Component Location and Configuration

Hardware Component	Installation Location and Configuration
Industrial Computer (V2I Hub)	• Shall be installed in the traffic cabinet on a flat surface
RSU (Radio)	• Shall be installed outside of the traffic cabinet • GPS antenna should be installed facing upwards, DSRC antennas installed facing downwards away from any metal mast arms below • Shall be sturdily mounted and centrally located to the intersection for optimal transmitting and receiving performance. • If the RSU cannot be mounted central to the intersection, it should be installed on a mast arm over-hanging into the intersection. • The RSU must be installed in a location with open sky for the GPS antenna to acquire GPS satellites. • Avoid installing near other radio frequency equipment to reduce signal interference • The RSU shall extend a minimum of six meters out from the base of the pole. • The transmitting range of RSU should be tested during installation to determine the number of RSUs needed and the optimal installation location • The RSU can be installed a maximum of 300 meters away from the PoE injector. • Do not recommend installing on span wire unless there are no other mounting options. • Metric tools may be required for installation depending on the RSU manufacturer • RSU can be installed separately from the other V2I Hub components during non-peak hours. • Do not power the RSU until all antennas have been connected.
GPS Antenna	• Shall be installed outside of the traffic cabinet • Shall be installed on the RSU facing upwards • Do not connect until the RSU has been mounted • Wrap the connection with electrical tape to prevent the possibility of precipitation penetrating the connection

Hardware Component	Installation Location and Configuration
(2) Radio Antennas	• Shall be installed outside of the traffic cabinet • Shall be installed on the RSU facing downwards • Do not connect until the RSU has been mounted • Wrap the connection with electrical tape to prevent the possibility of precipitation penetrating the connection
Traffic Signal Controller	• Installed in the traffic cabinet. • Connected to the network or V2I Hub via Ethernet
Ethernet Cable 5	• A small portion of this cable will be installed inside the traffic cabinet, while a majority of the cable will be run outside through conduit to connect to the RSU. • It is recommended that this cable be field terminated to prevent damage to the RJ-45 plugs during cable routing.
Ethernet Cable 4	• Shall reside inside the traffic cabinet • Depending on the size of the traffic cabinet and how closely all hardware is mounted, this cable will likely be less than five feet long.
Ethernet Cable 3	• Shall reside inside the traffic cabinet • Depending on the size of the traffic cabinet and how closely all hardware is mounted, this cable will likely be less than five feet long.
Ethernet Cable 2	• Shall reside inside the traffic cabinet • Depending on the size of the traffic cabinet and how closely all hardware is mounted, this cable will likely be less than five feet long.
Ethernet Cable 1	• Shall reside inside the traffic cabinet • Depending on the size of the traffic cabinet and how closely all hardware is mounted, this cable will likely be less than five feet long.
Surge Protector	• Shall reside inside the traffic cabinet • Shall be installed as closely to a ground termination as possible • A cable grounding the surge protector to the traffic cabinet ground termination is required.
Ethernet Switch	• Shall reside inside the traffic cabinet on a flat surface

Hardware Component	Installation Location and Configuration
(3) Power Outlets	• A power converter or power strip may be required if three power outlets do not exist.

Installation of the hardware components identified Table 8 should take no more than a few hours. It is recommended that all cables be labeled on each end to identify where each connection shall be made and for all cables to be dressed appropriately after the installation in complete. This will prevent configuration issues and will reduce the time to troubleshoot the system if required.

If the deployment requires the installation of poles, pole bases, or mast arms, it is recommended these efforts are coordinated ahead of time and installed prior to installing the components that reside in the traffic cabinet.

Integration

After the installation is complete, the integration process can begin. Integration is required to confirm all subassemblies are working with one another as expected and to confirm the system is ready for testing. Integration will vary by site location as the physical integration checks are dependent upon the characteristics of the installation. It is recommended to perform an integration check-out directly after the system has been installed and with the presence of a certified traffic signal technician appointed by the city or contractor. Below is a list of integration checks to be performed prior to testing.

1. Verify all components are securely installed.
2. Using a multi-meter, verify the voltage for each of the power outlets inside the Traffic Cabinet. The voltage should be between 110 and 120 VAC, if not, contact the authorizing municipality for assistance.
3. Using a cable-tester, verify each end of Ethernet Cable 5 was terminated correctly.
4. Once the Ethernet Switch has been powered on, view the indicator lights to confirm the unit is receiving power, per the instruction manual.
5. Once the V2I Hub has been powered on, view the indicator lights to confirm the unit is receiving power, per the instruction manual.
6. Once the PoE Injector has been powered on, view the indicator lights to confirm the unit is receiving power, per the instruction manual.
7. Once the RSU has been powered on, view the indicator lights to confirm the unit is receiving power, per the instruction manual.
8. After making the Ethernet Cable 1 connection between the V2I Hub and the Traffic Signal Controller (TSC), verify the traffic light remains in the operational mode.
9. Refer to the V2I Hub Software Configuration Guide for software integration checks.

Once these recommended integration checks have been completed, testing can proceed.

Testing

After verifying the basic functionality of the hardware components during integration, refer to the *V2I Hub Software Configuration Guide (Battelle, 2018)* for instructions on testing software applications and functionality.

Chapter 7. Post Deployment

Proceeding field deployment, is the post deployment phase, which involves operating, monitoring, and maintaining the system. Although most of the deployment may be completed, a minimal effort should be required to maintain the V2I Hub. For additional information on the operations, monitoring, and maintenance of the V2I Hub, refer to the *V2I Hub Software Configuration Guide*.

Operations

Following the V2I Hub system being installed and tested, there are not any day-to-day operation requirements for keeping the system active or functioning. The level of effort and resources spent on operations are dictated by the deploying agency. There may be interest in the deploying agency to maintain operation records, create operation reports, train other staff, or developing training materials; however, this is not required.[4]

While there are not any requirements for operations, associated risks still exist. Example risks that may need to be resolved include the following:

- Software updates – the need for a software update to be installed or a software bug may need to be resolved.
- Hardware replacement – adverse weather conditions or traffic related accidents could cause damage to the hardware installed.
- Construction – the physical installation of the hardware could be impacted such as the hardware being temporarily uninstalled or moved.

Monitoring

There are not any requirements for monitoring the V2I Hub, post deployment. Assuming the system remains undisturbed, it is recommended that the V2I is occasionally checked and monitored to confirm functionality. If a connection exists between the TMC and the V2I Hub, the system can be monitored remotely. If this connection does not exist, a localized system monitoring will be required. This would include the following:

- Checking the indicator lights on the RSU installed in the field.
- Checking the indicator lights on the components installed inside the traffic cabinet.
- Accessing the V2I Hub Admin Portal.

If there is a need to monitor the components inside the traffic cabinet, consult a City official or an authorized third-party contractor for access to the cabinet.

Potential risk that exist for not monitoring the system include:

- If the system lost any sort of functionality, it would not be known to the deploying agency unless the Administration Portal was monitored or a site visit was conducted.

Maintenance

If system maintenance is required, it is likely assistance will be needed from the agency who helped install and deploy the system. While there are not maintenance requirements for the V2I Hub, the deploying agency can elect to include maintenance in part of their contract with the agency performing the deployment. During system maintenance, a traffic engineer may be requested by the deploying agency to establish maintenance procedures, records, reports, and a strategy for performing maintenance. There may be a need for system maintenance if new applications are desired or if there is a need to replace a specific hardware component.[4] Construction also presents the potential risk for required software maintenance as construction would cause the MAP file for the site location to be updated accordingly. Refer to ISD Message Creator tool documentation located in the U.S. DOT CV Tools Library (https://webapp.connectedvcs.com/) for instructions on how to create or modify a MAP file. For additional information on system maintenance and support, refer to Chapter 4. Maintenance and Support in the V2I Hub Software Configuration User Guide.

Chapter 8. Deployment Checklist

The V2I Hub Deployment Checklist has been developed as a guide to help provide direction and to ensure a successful deployment of the V2I Hub.[5]

Project Initiation

- ☐ Define project objectives, scope, how results will be measured, and lifespan.
- ☐ Determine Connected Vehicle Safety Applications, messages, functionality, V2I Hub plugins, and supporting software needed to accomplish project objectives.
- ☐ Identify required hardware.
- ☐ Develop initial budget.
- ☐ Develop initial schedule.
- ☐ Identify constraints, risks, and mitigations/alternatives.
- ☐ Identify project work areas and team.
- ☐ Project team kickoff Meeting.
- ☐ Update with new information as appropriate.

Coordination with Supporting Agencies

- ☐ Kickoff meeting
- ☐ Identify and confirm stakeholders requiring approval or coordination (e.g., State/City/County, utility agencies, business or private properties impacted).
- ☐ Identify approvals and permits needed.
- ☐ Determine if design plans are required and submittal requirements for preliminary, advanced, final, and as-built plans.
- ☐ Obtain jurisdiction approval process and review times for development of project schedule.
- ☐ Obtain any existing roadway, intersection, and traffic signal design plans.
- ☐ Obtain current traffic signal timing plans and Phase to Lane Mapping (PTLM) assignments.
- ☐ Ascertain what equipment is in the field; including make, model, and firmware version.
- ☐ Determine FCC permit licensee (typically the jurisdiction).
- ☐ Discuss potential locations for mounting the Roadside Unit (RSU) and hardware for mounting.
- ☐ Determine any loading or structural analyses required for mounting the RSU on existing structures, specifically traffic signal mast arms or span wires. RSUs typically weigh less 15 pounds, excluding mounting hardware. Confirm weight with RSU vendor.

- ☐ Determine approval requirements for equipment, specifically V2I Hub and the RSU.
- ☐ Determine any specific requirements for grounding or a surge protective device on the Ethernet cable to the RSU for lightning protection.
- ☐ Determine any requirements for traffic management or control plans during installation, and the process and approval requirements for any lane closures.
- ☐ Determine field inspection and installation approval requirements.
- ☐ Determine the requirements for the Ethernet cable connecting the RSU to utilize existing conduit and anticipated feasibility.
- ☐ Work with IT networking personnel to determine the protocols for accessing V2I Hub and the RSU in the field, and to enable them to retrieve external information (e.g., position correction data, security certificates, local weather information, etc.).
- ☐ Site visit to confirm equipment in the field, RSU mounting options and obstructions, and junction box locations and condition of conduit.
- ☐ Update scope and work plan as appropriate.

Design

- ☐ Refine the Connected Vehicle Safety Applications, messages, functionality, V2I Hub plugins, and supporting software identified during project initiation.
- ☐ Security is a fundamental part of CV technology and will need to be part of the design from the beginning, specifically to meet the requirements of the Security Credential Management System (SCMS).
- ☐ Determine how software updates can be implemented remotely, with minimal downtime, and without impacting traffic signal operations.
- ☐ Determine RSU reception range required for project connected vehicle (CV) applications.
- ☐ Determine if more than one RSU is required to cover project area.
- ☐ Determine RSU mounting location and hardware required.
- ☐ Determine if existing equipment is compatible and meets requirements to support CV technology (e.g., traffic signal controller).
- ☐ Identify if the necessary infrastructure is in place (e.g., traffic signal poles to mount the RSU, conduits for Ethernet cable, etc.) or if new infrastructure will need to be constructed.
- ☐ Identify hardware and equipment list for procurement.
- ☐ Develop design plan sheets as required by approving jurisdiction.
- ☐ Develop performance requirements (e.g., uptime, RSU reception range, maximum packet loss, lag, design life, etc.).
- ☐ Develop Test/Verification Plans to confirm and document system operations, CV Application functionality, and network connections.
- ☐ Identify equipment needed for testing (e.g., in-vehicle device for transmission and receipt of CV messages).

- ☐ Develop Operations and Maintenance Plan as needed (e.g., equipment status, uptime, maintenance plan, field inspection and testing intervals, equipment replacement plan, software update plan, etc.).

Approvals and Permits

- ☐ Security Credential Management System (SCMS).
- ☐ Obtain Federal Communications Commission (FCC) Spectrum Permit for use of the protected 5.9GHz spectrum used by DSRC radios.
- ☐ Obtain necessary jurisdiction approvals and permits.
- ☐ Obtain equipment and hardware approval.

Equipment and Procurement

- ☐ Hire traffic signal contractor to procure equipment (for contractor installations).
- ☐ Industrial computer to run the V2I Hub software platform.
- ☐ RSU Dedicated Short Range Communications (DSRC) radio with GPS attachment.
- ☐ Power over Ethernet (PoE) adapter (may be provided with RSU).
- ☐ RSU mounting hardware (for pole, span wire, or mast arm).
- ☐ Ethernet surge protector for lightning protection (if required by jurisdiction).
- ☐ In-cabinet mounting hardware or ground wires (if required by jurisdiction).
- ☐ Up to 3 Cat5e or Cat6 Ethernet cables (patch cables for connecting equipment in cabinet, less than 5 feet in length).
- ☐ Shielded, outdoor-rated, Cat5e or Cat6 Ethernet cable (for connecting the RSU and traffic signal controller, length varies by deployment).
- ☐ Equipment for an Internet and Transportation Management Center (TMC) connection, if needed.
- ☐ Associated or upgraded equipment, as needed (e.g., compatible traffic signal controller, Ethernet switch, etc.).
- ☐ Any additional hardware or equipment identified in the design.
- ☐ In-vehicle device for testing/verifying message transmission.

Pre-Deployment Development and Preparation

- ☐ Custom V2I Hub plugins – Develop to support new project applications, functionality, and hardware connections & message translation (if needed).
- ☐ Development of backend software at the TMC for the reception and transmission of messages and data with V2I Hub.
- ☐ Develop intersection geometry input file for MAP Plugin. Refer to the ISD Message Creator tool documentation located in the U.S. DOT CV Tools Library (https://webapp.connectedvcs.com/) for instructions for instructions on how to create a MAP file.
- ☐ Develop PTLM XML input file for SPaT Plugin.
- ☐ Assign IP addresses to RSU and V2I Hub in accordance with the IP address schema used by the devices in the traffic cabinet. The RSU must be assigned its IP address in an environment where its GPS antenna has an open view of the sky.

- ☐ Document all device IP addresses and configuration settings.
- ☐ Install the RSU software compliant with the RSU 4.1 specification on the RSU.
- ☐ Obtain RSU security certificates and install on RSU per RSU manufacturer guidance
- ☐ Install V2I Hub software on industrial computer by downloading it from the Open Source Application Development Portal. Refer to the V2I Hub Application Software Installation section of the V2I Hub Application Software Installation section of the *V2I Hub Software Configuration Guide*.
- ☐ Configure V2I Hub, RSU, and plugins. Refer to the V2I Hub Application Software Installation section of the V2I Hub Application Software Installation section of the *V2I Hub Software Configuration Guide*.
- ☐ Configure network connections and ports for remote access to V2I Hub and the RSU, and to enable these devices to access information external to the TMC (e.g., position correction data, security certificates, etc.).
- ☐ Load the MAP file onto the V2I Hub. Refer to the MAP Plugin Configuration section of the *V2I Hub Software Configuration Guide*.
- ☐ Verify plugin message activity if associated equipment is available (e.g., traffic signal controller).
- ☐ Test software and field equipment functionality and message transmission to a representative in-vehicle device in the lab prior to field deployment, as feasible with available equipment. Note: If the application being deployed requires an OBU test the GPS signal and verify the quality of DSRC reception required.
- ☐ Create a block or wiring diagram of all the connections made between components for use during the installation.

Field Verification Prior to Installation

- ☐ Connect V2I Hub, RSU, traffic signal controller, and maintenance computer prior to mounting hardware to confirm operation.
- ☐ Configure traffic signal controller.
- ☐ Verify communications between traffic signal controller, V2I Hub, RSU, and TMC.
- ☐ Verify plugin message activity.
- ☐ Verify transmission of messages to a representative in-vehicle device.
- ☐ Verify remote access to V2I Hub and the RSU.
- ☐ Verify V2I Hub is able to retrieve external information as needed (e.g., position correction data, security certificates, local weather information, etc.).
- ☐ Verify field conditions are consistent with design plans or proposed equipment locations.
- ☐ Confirm line-of-sight without physical or vegetation obstructions between proposed RSU location(s) and all roadway approaches necessary for CV applications.

Field Installation

- ☐ Schedule utility location if underground work is anticipated.
- ☐ Schedule deployment and jurisdiction participation/oversight as needed.

- ☐ Schedule/Coordinate traffic management, including lane closures and law enforcement support (if needed).
- ☐ Field verification of equipment locations with jurisdiction may be needed if obstacles require shifting from their planned locations.
- ☐ Install equipment and Ethernet cable connections.

System Test, Inspection, and Approval

- ☐ Verify transmission of messages to a representative in-vehicle device (OBU).
- ☐ Verify signal phase and timing on in-vehicle device matches what is displayed on the traffic signal heads. Note: When select traffic signal controllers are sent into flash mode, the SPaT data transmitted from the controller may not be representative of the flash mode it entered as it may still display the SPaT information from the traffic signal program prior to entering flash mode.
- ☐ Verify remote access to V2I Hub and the RSU.
- ☐ Passes Test/Verification Plan developed as part of the design documents.
- ☐ Verify RSU transmission reception range meets project CV application requirements on all roadway approaches.
- ☐ Jurisdiction inspection and approval, as required.
- ☐ Develop and submit as-built plans, as required.

Operations and Maintenance

- ☐ Implement Operations and Maintenance Plan.
- ☐ Maintain records of equipment, status, costs, and lifecycle according to agency asset management practices.
- ☐ Follow-up with stakeholders for discussing operational value and enhancements.

Appendix A. Acronyms

ASC	Actuated Signal Controller
CV	Connected Vehicle
BSM	Basic Safety Message
DSRC	Dedicated Short-Range Communications
FCC	Federal Communications Commission
GPS	Global Positioning System
IVP	Integrated V2I Prototype
MMITSS	Multi-Modal Intelligent Traffic Signal Systems
OBU	On-Board Unit
OSADP	Open-Source Application Development Platform
PoE	Power over Ethernet
PTLM	Phase to Lane Mapping
RSU	Roadside Unit
SPaT	Signal, Phase, and Timing
TIM	Traffic Incident Message
TSC	Traffic Signal Controller
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

Appendix B. References

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