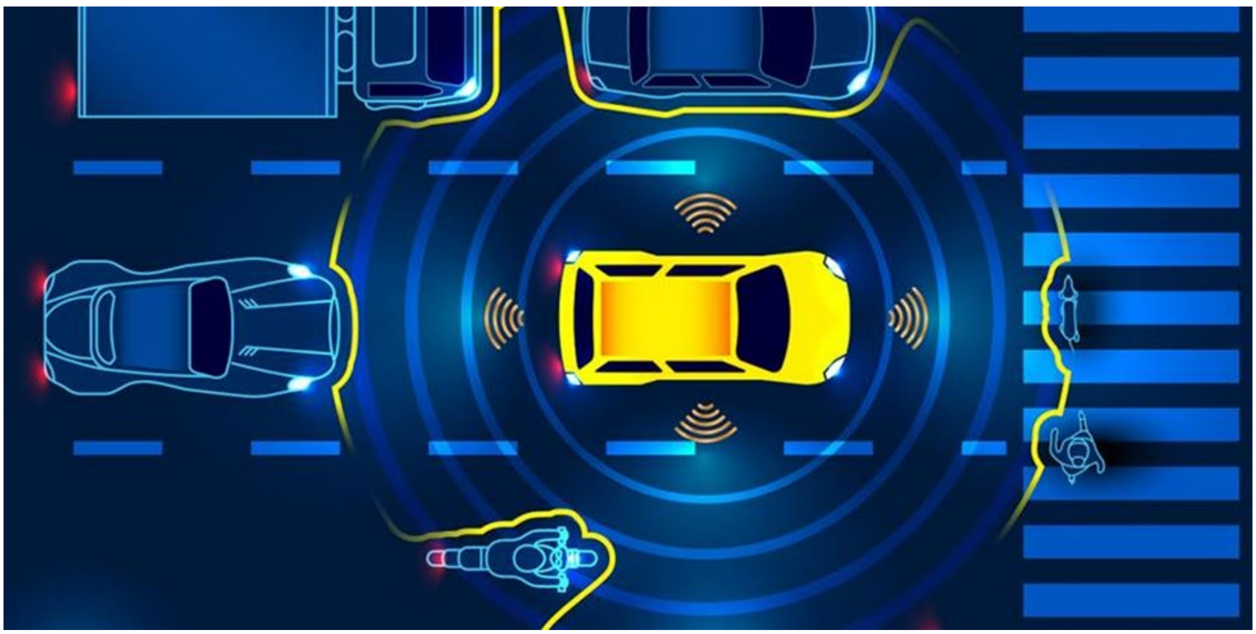
CONNECTED INTERSECTIONS PROGRAM: PROGRAM MANAGEMENT AND TECHNICAL SUPPORT

Connected Intersection Guidance Document

December 2022



Prepared by

wsp

Contents

Tables

Figures

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AGET	Assured Green End Time
AGP	Assured Green Period
ATC	Advanced Traffic Controller
ATMS	Advanced Traffic Management System
ATSPM	Automated Traffic Signal Performance Measures
BSM	Basic Safety Message
C-ITS	Cooperative Intelligent Transportation Systems
C-V2X	Cellular-Vehicle-to-Everything
CA	Certificate Authority
CAMP	Crash Avoidance Metrics Partnership
CAT	Cooperative Automated Transportation
CAT5	Category 5
CI	Connected Intersection
CIMMS	Connected Intersection Message Monitoring System
CORS	Continuously Operating Reference Station
CTI	Connected Transportation Interoperability
CV	Connected Vehicle
CV PFS	Connected Vehicle Pooled Fund Study
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
DTLS	Datagram Transport Layer Security
ECLA	External Control Local Application
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FRN	FCC Registration Number
FYA	Flashing Yellow Arrow
GA	Green Arrow
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSM	Hardware Security Module
HZ	Hertz
IOO	Infrastructure Owner Operator
IPv6	Internet Protocol Version 6
ID	Identification
IEEE	Institute of Electrical and Electronic Engineers
IOO	Infrastructure Owner Operator
IT	Information Technology
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
ITS America	Intelligent Transportation Society of America
JSON	JavaScript Object Notation
MMITSS	Multi-Modal Intelligent Traffic Signal System
ms	millisecond
NCHRP	National Cooperative Highway Research Program
NEMA	National Electrical Manufacturers Association
NRTM	Needs to Requirements Traceability Matrix
NTCIP	National Transportation Communications for Intelligent Transportation Systems Protocol
NTP	Network Time Protocol
NTRIP	Network Transport of RTCM via Internet Protocol
OBU	On-Board Unit
OEM	Original Equipment Manufacturer

PCAP ..... Packet Capture
RA ..... Red Arrow
RLVW ..... Red Light Violation Warning
RSM ..... Road Safety Messages
RSU ..... Roadside Unit
RTK ..... Real-Time Kinematic
RTCM ..... Radio Technical Commission for Maritime Services
SCMS ..... Security Credential Management System
SPaT ..... Signal Phase and Timing
SRM ..... Signal Request Message
SSM ..... Signal Status Message
TIM ..... Traveler Information Message
TLS ..... Transport Layer Security
TMC ..... Transportation Management Center
TMS ..... Traffic Management System
TSC ..... Traffic Signal Controller
TSCBM ..... Traffic Signal Controller Broadcast Message
UMTRI ..... University of Michigan Transportation Research Institute
URL ..... Uniform Resource Locator
USDOT ..... United States Department of Transportation
UTC ..... Coordinated Universal Time
V2X ..... Vehicle-to-Everything
VAC ..... Volts of Alternating Current
VDC ..... Volts of Direct Current
WAVE ..... Wireless Access in Vehicular Environments
WRA ..... Wireless Access in Vehicular Environments Routing Advertisement
WSA ..... Wireless Access in Vehicular Environments Service Advertisement
WZDx ..... Work Zone Data Exchange
YA ..... Yellow Arrow

Executive Summary

A connected intersection (CI) is defined as an infrastructure system that broadcasts messages with signal phase and timing (SPaT) data, mapping information, and position correction data that has been tested and verified to be standards compliant and to accurately represent the current status of the intersection. These broadcast messages are intended to be received by any on-board unit (OBU) receiver for in-vehicle applications operating on connected vehicles, which rely on CI data being communicated to accurately identify the status of the intersection signal controls and be able to determine the vehicle's lane of travel.

The messages broadcast from CIs needs to be accurate and strictly conform to national requirements and standards for data exchanges in order to eventually allow production vehicles that approach any CI to successfully receive and use that data that is broadcast. As such, the success of CIs relies on nationally consistent deployment, testing, and validation processes. The purpose of this document is to provide comprehensive guidance to support CI deployments and ensure that data broadcast are standards compliant, accurate, secure, and thoroughly tested.

A number of standards and resources are available to support the deployment of CIs, such as the *SAE J2735 V2X Communications Message Set Dictionary*; *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide;* and *CTI 4001 v01 Roadside Unit (RSU) Standard.* This document does not copy relevant information from all applicable standards and resources, but instead references those documents and provides additional explanations as they are needed to help interpret and apply the information in these documents. This approach helps ensure that practitioners are referencing the latest available versions of information.

As with the standards, CI technologies and deployment processes are expected to evolve over time. New strategies, approaches, and industry collaboration may result in modifications to CI requirements, as well as associated expectations for security, monitoring, and testing. These changes, as well as increased practitioner familiarity with CIs, are likely to streamline deployment of CIs. Ultimately, this Guidance document is an early attempt to summarize an approach for deploying CIs to support unfamiliar practitioners and is not expected to be a document that will be needed in perpetuity. Instead, while updated versions of this document may be released, increased practitioner familiarity combined with increased deployment and more user-friendly and off-the-shelf technologies and tools are expected to reduce the need for CI deployment guidance over time.

OVERVIEW OF THIS GUIDANCE

Deploying a CI will be a complex effort for first-time deployers given the variety of standards, resources, and technologies that a practitioner needs to understand and apply. This Guidance is intended to facilitate the CI deployment process by following an approach that should be familiar to practitioners who have experience deploying traditional signalized intersection. Specifically, this Guidance is organized into eight steps, which are summarized below.

- <u>Step 1: Assemble Data and Information</u>. This step focuses on preparation to enable CI deployers to better understand existing conditions at the intersection and remaining needs by documenting information. For example, this step includes understanding movement control types, signal control equipment, network readiness, and agency Advanced Traffic Management System (ATMS) capabilities.

- Step 2: Determine Capabilities and Options to Meet CI Requirements. This step builds on Step 1 by understanding the components needed at a CI, and what options (e.g., upgrading existing equipment or procuring new equipment) make the most sense given existing agency systems and capabilities. For example, this step considers the readiness and capabilities of signal controllers, RSUs, and external control local application (ECLA), and increases understanding of security and staffing needs.
- Step 3: Determine Procurement Specifications. This step leverages the documentation practitioners completed in Steps 1 and 2 to develop procurement specifications that will support procurement in Step 4 of the CI deployment process. This guidance is expected to be adapted based on local constraints, conditions, and the specific goals for the CI deployment. This step covers specifications for CI components including RSUs, ECLA, and test equipment, as well as field installation activities.
- Step 4: Procure System Components. This step leverages procurement specifications developed in Step 3 and includes additional considerations while procuring CI system components for a deployment, such as scalability, type of procurement, and staffing needs.
- Step 5: Assemble and Test System Off-line (Bench Testing). This step helps practitioners understand the role of bench testing and supports development of a local approach for testing all CI requirements using a combination of bench testing and field validation that is flexible for the local conditions, constraints, and available resources. Specifically, bench testing includes reviewing testing resources, developing a local approach for bench testing, assembling and configuring the bench test environment, and collecting and analyzing bench test data.
- Step 6: Deployment and Field Validation. This step describes field validation testing on operational intersections, which will allow the deploying agency to confirm the actual operation and performance of the specific intersection and to verify that the system is correctly configured for the specific intersection. Specifically, this step includes information about CI equipment installation, a staffing, equipment, and data collection approach to field validation, and collection and analysis of data.
- Step 7: Vehicle Verification. This step describes how vehicle verification may be conducted to confirm CI operations for original equipment manufacturer (OEM) production vehicles.
- Step 8: Operations and Monitoring. This step describes normal CI operations and monitoring that is necessary to ensure ongoing accuracy and functionality of CI equipment and broadcasts.

Practitioners are encouraged to review all steps in this Guidance, with a recognition that some Guidance steps may not be applicable for repeat deployers who are more familiar with CIs. Guidance within each step is structured to provide an overview of the topic, clear guidance statements, and a basis with supporting rationale and references to standards or other resources.

The Connected Vehicle Pooled Fund Study is soliciting input from any users of this Guidance to improve upon this document in future versions. Specifically, any reactions or feedback to the content in this document is encouraged. This feedback should be sent to CV PFS members or the CV PFS Program Coordinator, Mallory Artusio, at martusio@virginia.edu.

1. Introduction

Transportation agencies in the past few years have started moving towards achieving connected intersections (CIs). A CI is defined as an infrastructure system that broadcasts signal phase and timing (SPaT) data, mapping information, and position correction data that has been tested and verified to be standards compliant and to accurately represent the current status of the intersection. These broadcasts are intended to be received by in-vehicle applications operating on connected vehicles, which will rely on the CI data being communicated to accurately identify the status of the intersection signal controls and be able to determine the vehicle's lane of travel.

It is generally the role of the Infrastructure Owner Operator (IOO) responsible for a signalized intersection to deploy and operate the technology to achieve the status of a CI. On-board units (OBUs) that receive and process data from CI may be operated by a public entity (e.g., local transit agency, IOOs, law enforcement, Fire and Rescue) or by privately owned vehicles operating either original equipment or aftermarket OBUs. The ability for an OBU to interpret the data broadcast by any CI relies on consistent deployment, testing, and validation of equipment and information according to established standards.

> This document provides guidance on the deployment of Connected Intersections (CIs) to support the broadcast of signal phase and timing (SPaT), intersection geometry, and position correction information required to support in-vehicle safety applications, such as Red-Light Violation Warning (RLVW). The goal is to ensure that data broadcast are standards compliant, accurate, secure, and thoroughly tested.

Deploying a CI will be a complex effort for first-time deployers given the variety of additional standards, resources, and technologies that a practitioner needs to understand and apply. A number of standards and resources are available to support the deployment of CIs, such as the *SAE J2735 V2X Communications Message Set Dictionary*; *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide; and CTI 4001 v01 Roadside Unit (RSU) Standard.* This document does not copy relevant information from all applicable standards and resources, but instead references those documents and provides additional explanations as they are needed to help interpret and apply the information in these documents. This approach helps ensure that practitioners are referencing the latest available versions of information.

This Guidance is intended to facilitate the CI deployment process by following an approach that should be familiar to practitioners who have experience deploying traditional signalized intersection. Use of this document and successfully completing each step outlined will help to ensure consistency across agencies. This document provides comprehensive guidance to support CI deployments and ensure that data broadcast are standards compliant, accurate, secure, and thoroughly tested.

The need driving this project was to help IOOs deploy CIs that meet or exceed minimum system performance needs to effectively communicate with applications operating in production vehicles, and address geographic and equipment variations, security, and message consistency. The guidance was developed based on research, reviews of technical resources, and experiences with transportation agencies that have deployed CIs, as well as CI testing activities conducted as a related part of this effort.

CI technologies and deployment processes are expected to evolve over time. New strategies, approaches, and industry collaboration may result in modifications to CI requirements, as well as associated expectations for security, monitoring, and testing. These changes, as well as increased practitioner familiarity with CIs, are likely to streamline deployment of CIs. Ultimately, this Guidance document is an early attempt to summarize an approach for deploying CIs to support unfamiliar practitioners and is not expected to be a document that will be needed in perpetuity. Instead, while updated versions of this document may be released, increased practitioner familiarity combined with increased deployment and more user-friendly and off-the-shelf technologies and tools are expected to reduce the need for CI deployment guidance over time.

1.1 DOCUMENT STRUCTURE AND TARGET AUDIENCE

This section describes the structure of the document and the target audience of the guidance CI deployment.

1.1.1 Document Structure

Following this document overview, the remainder of this section will present an overview of CI system components, describe the stages of deploying a CI, and reference applicable standards.

Section 2 contains the guidance created by the Connected Vehicle Pooled Fund Study (CV PFS) Connected Intersections Program Project Panel and supporting contractors. The guidance is presented in eight steps that follow general activities that are common when deploying CIs.

1.1.2 Target Audience

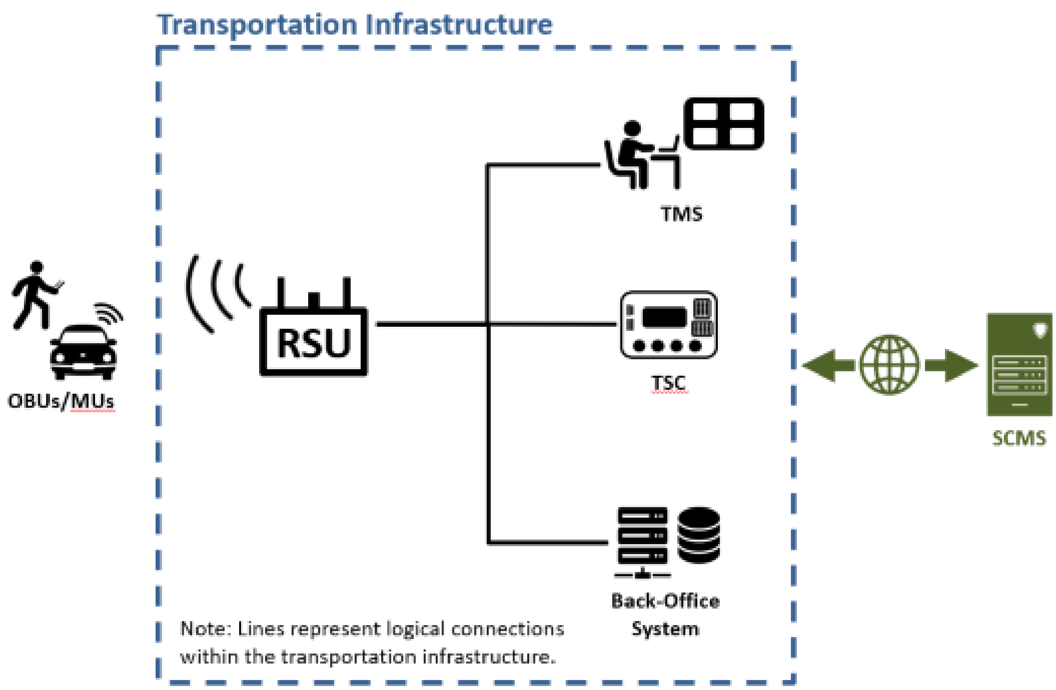
This document was created for:

- IOO staff that are deploying, operating, or updating CIs.
- IOO managers responsible for allocating funding and/or making high-level decisions about deployment of CIs.
- Contractors that deploy, operate, or update CI equipment or messages on behalf of IOOs.

1.2 OVERVIEW OF CONNECTED INTERSECTIONS

1.2.1 Components of Connected Intersections

This section provides a high-level explanation of the key components of CIs. These components include a roadside unit to interface with the traffic signal equipment and provide broadcasts of SPaT, mapping, and position correction information that is accompanied by security credentials. A high-level view of the vehicle-to-everything (V2X) system for CIs is shown in Figure 1.



Source: CTI 4001 v01 RSU Standard

Figure 1. High-Level Depiction of the Connected Intersections Vehicle-to-Everything System

Roadside Unit

The *CTI 4001 v01 RSU Standard* defines a roadside unit as a transportation infrastructure communications device located on the roadside that provides V2X connectivity between OBUs / mobile units and other parts of the transportation infrastructure including traffic control devices, traffic management systems, and back-office systems. The standard notes that devices that are not part of the transportation infrastructure, such as cellular base stations or satellites, are not RSUs.

RSUs are the key element of a CI as they exchange data with vehicles (and other road users) and other infrastructure elements. RSUs can receive messages from vehicles and other road users, and then forward these messages to transportation infrastructure elements (e.g., traffic management systems (TMSs), traffic signal controllers (TSCs), back-office data storage) to request signal priority and also provide information about real-time traffic conditions. Similarly, RSUs broadcast real-time critical infrastructure information, including SPaT and information about the intersection geometry (i.e., MAP) over the air to vehicles and other road users to inform travelers of current and upcoming traffic signal indications.

SPaT Message

The SAE J2735 SPaT message provides real-time status information about a signalized intersection, including dynamic signal indication and timing information for the individual signal groups at the intersection.

The data included in the SPaT message enables in-vehicle applications to understand the current and near future status of the signal controller (i.e., red, yellow, green, green arrow, etc.) as they approach a CI. Once the status of the signal controller is known, applications such as Red-Light Violation Warning (RLVW) can determine appropriate notifications to be delivered to drivers, such as alerting drivers who are not decelerating that the signal indication is currently red.

Position Correction Message (RTCM)

The SAE J2735 Radio Technical Commission for Maritime Services (RTCM) corrections message includes differential position correction for GPS and other radio navigation signals as defined by the RTCM in its standards. These messages are prepared for broadcast to vehicles and then re-constructed and used directly by positioning systems within the vehicle to increase absolute and relative accuracy position estimates, thus minimizing the effects of GPS error caused by atmospheric conditions. The *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide* notes that experimental data has shown that it takes about four received RTCM messages to obtain sufficient position accuracy. RTCM corrections messages transmission rates were initially set at one time per second (1 Hertz (Hz)). Local terrain, antenna height and other factors may increase the frequency needs to five times per second (i.e., 5 Hz). More details are available in the CTI 4501 v01.01 document.

The general concept of the RTCM message is that a base station with a known location (the location may be known by either by surveying in the station location or operating a GPS receiver for a long continuous period of time) continuously receives satellite signals and determines a current latitude / longitude position given the current atmospheric conditions. The base station then compares the position determined with the current atmospheric conditions to the known location and computes a correction factor that corrects the current calculated position to the known position. This correction factor is the RTCM message that can be sent out to vehicles. Early testing has shown that using RTCM corrections can improve vehicle position determination and this higher location accuracy can support the OBU in determining more reliable lane level positioning of vehicles. Note that RTCM correction is not intended to address challenges with urban canyons or lack of sufficient GPS satellites in view. Creation of the RTCM message may either be done by operating a base station at the intersection, or by retrieving the RTCM from an on-line source, or by a central calculation at the TMC.

MAP Message

The SAE J2735 standard includes a specification for a MAP message that includes information about intersection and road geometries for V2X systems. Specifically, the MAP message is a standardized encoding of map data designed to provide location references for other SAE J2735 messages (e.g., the SPaT message). It can provide lane information for up to 32 intersections and 32 non-intersection road segments. For the purposes of SPaT-enabled applications, it would typically contain the lane information for a single intersection.

The MAP message contains the latitude/longitude of centerline node points for each ingress and egress lane at the intersection. Applications compare these node points to vehicle positions to determine the lane of travel. The MAP message also allows the on-board applications to determine which part of the SPaT message (i.e., signal group) applies to the movement the vehicle will make at the intersection. Using this, the on-board application can interpret the SPaT messages that it receives and determine if the current state of the signal controlling the vehicle movement. Applications compare these node points to vehicle positions to determine the lane of travel.

Because the on-board application will use the coordinates of the MAP message node points to compare to current and previous locations of the vehicle, there is a need for high levels of accuracy. According to the *CTI 4501 v01.01 CI Implementation Guide*, node positions must be accurate to within ± 0.2 meters of the actual node location.

Security Credentialling

A unique aspect of a V2X system is that most OBUs need to remain anonymous to protect the privacy of the vehicle operator and owner. Conventional IT security mechanisms require a pre-established trust relationship between the data sender and the data receiver. This is not practical for a V2X system, so for vehicles to securely exchange data with other unknown (anonymous) devices, a mechanism is required for RSUs, OBUs, and other V2X devices to verify received messages are from a "trusted" source; this helps prevent the broadcasting and use of malicious fake or misleading data. This mechanism enables vehicles to exchange data with each other and the infrastructure while remaining anonymous.

A V2X Security Credential Management System (SCMS) provides anonymous trust by enabling the issuance of digital certificates, based on Institute of Electrical and Electronics Engineers (IEEE) 1609.2, to approved devices. Devices use these certificates to sign messages they broadcast, and receiving devices verify the signatures to ensure messages are from a trusted source. Messages are signed using certificates generated and provided from a known and trusted Certificate Authority (CA) (certificate issuer).

The CI uses certificates for devices to sign messages they broadcast, and receiving devices verify the signatures to ensure messages are from a trusted source. SCMS certificates are managed by an entity called SCMS Manager and are valid for a fixed time and must be periodically replenished.

Operations of Connected Intersections components

The two primary roles of CI operations are to maintain continuous broadcasts of accurate and secured messages containing data (i.e., SPaT, MAP, and RTCM messages with security credentials) and to perform periodic updates as new conditions, technologies, standards, or issues are introduced. Automated and manual monitoring functions will be needed to detect situations when errors occur (e.g., signal controller data does not match SPaT broadcasts) or conditions change (e.g., incidents, maintenance, or construction activities) that result in broadcast data being inaccurate or inconsistent with real-time conditions. Additionally, testing and validation activities will also likely be needed when updates or changes occur, as well as on a routine basis to ensure ongoing CI functionality and accuracy.

External Control Local Application (ECLA)

While the simplest approach for delivering SPaT data to the RSU would be a direct connection from the Signal Controller to the RSU, there are a variety of reasons why additional software may be required between the two systems. This additional software is referred to in the CTI 4501 v01.01 CI Implementation Guide as an External Control Local Application (ECLA) and may require a dedicated hardware server or may be housed and operated on an existing server. In addition to supporting the creation and/or communication of SPaT messages to the RSU, the ECLA may perform other functions, such as processing Basic Safety Messages (BSMs), processing signal priority requests, and storing MAP messages.

External Components Required for Connected Intersections

Finally, there are existing devices that the CI will depend upon to function, including the traffic signal controller (TSC), backhaul communications, and power, as well as the traffic signal infrastructure (e.g., signal controller, signal heads, poles, and cabinet). While these elements are typically already present at the intersection, they may require some modifications to fully support the CI. The guidance in this document will offer support to understand the role and requirements of these external components.

1.2.2 Stages of Connected Intersections Deployment and Operations

Developing the Connected Intersection

The first stage of deploying a CI involves preparation to better understand and document existing conditions at the intersection, as well as becoming familiar with CI standards. For example, this includes understanding movement control types, intersection geometry, signal control equipment, network readiness, and agency Advanced Traffic Management System (ATMS) capabilities.

This stage also considers what components will be needed at a CI, including what options (e.g., upgrading existing equipment or procuring new equipment) make the most sense given existing agency systems and capabilities. For example, this stage considers the readiness and capabilities of TSCs, RSUs, and ECLA, and increases understanding of security and staffing needs.

This stage concludes with the development of procurement specifications for CI system components (and staff support, as necessary) and procurement of CI system components. Procurement considerations that might impact CI deployment include scalability, type of procurement, and staffing needs.

Testing and Validating the Connected Intersection

After procurement, a series of testing is conducted prior to and after deployment of CI system components. First, off-line (bench) testing occurs in a shop environment prior to deploying components at the intersection. Next, CI system components are deployed in the field, which will require agency or contractor staff with technical skills and understanding to configure and integrate the CI equipment in the field with existing systems. Subsequently, field validation allows the deploying agency to confirm the actual operation and performance of the specific intersection and to verify that the system is correctly configured for the specific intersection.

Verifying the Connected Intersection to Gain Automobile Manufacturer Trust

In order for the automobile manufacturers that are anticipated to develop in-vehicle RLVW applications in production vehicles to have trust that CIs are broadcasting accurate, consistent, reliable, secure, and standards compliant messages, a final step in deploying CIs is to participate in a vehicle verification process. This process will ensure that the CI can be trusted by original equipment manufacturer (OEM) production vehicle applications. The process and roles for this verification are still being developed, but preliminary guidance is included in this report.

Operating the Connected Intersection

The final stage entails normal CI operations and the monitoring that is necessary to ensure ongoing accuracy and functionality of CI equipment and broadcasts. For example, this includes automated malfunction monitors, manual monitoring to identify disruptions at the CI, software or technology updates, routine maintenance, and ongoing testing and validation of CI accuracy and functionality.

1.2.3 Key Standards and Guidance Resources for Connected Intersections

There are a variety of resources available for practitioners to reference as they deploy a CI. The list below highlights several critical resources, which should be downloaded to facilitate the CI deployment process, as they contain critical information and will be frequently referenced in this guidance. These documents may experience frequent updates and therefore it is recommended that readers check the source websites frequently for newest versions.

- *SAE J2735 V2X Communications Message Set Dictionary*[1]. Specifies a message set, and its data frames and data elements, for use by applications that use V2X communications systems.
- *Connected Transportation Interoperability* (CTI) *4501 v01.01 Connected Intersections (CI) Implementation Guide*[2]. Standardizes the key capabilities and interfaces for a CI, and addresses the ambiguities and gaps identified by early deployers and provide enough guidance to generate messages and develop applications for signalized intersections that are truly interoperable across the United States, especially for automated transportation systems.
- *Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard*[3]. A non-proprietary, communications-agnostic, industry consensus standard for RSUs, a transportation infrastructure communications device that is a key part of a Cooperative Intelligent Transportation Systems (C-ITS) transportation environment.

[1] Available at: https://www.sae.org/standards/content/j2735_202007/
[2] Available at: https://www.ite.org/technical-resources/standards/connected-intersections/
[3] Available at: https://www.ite.org/technical-resources/standards/connected-intersections/

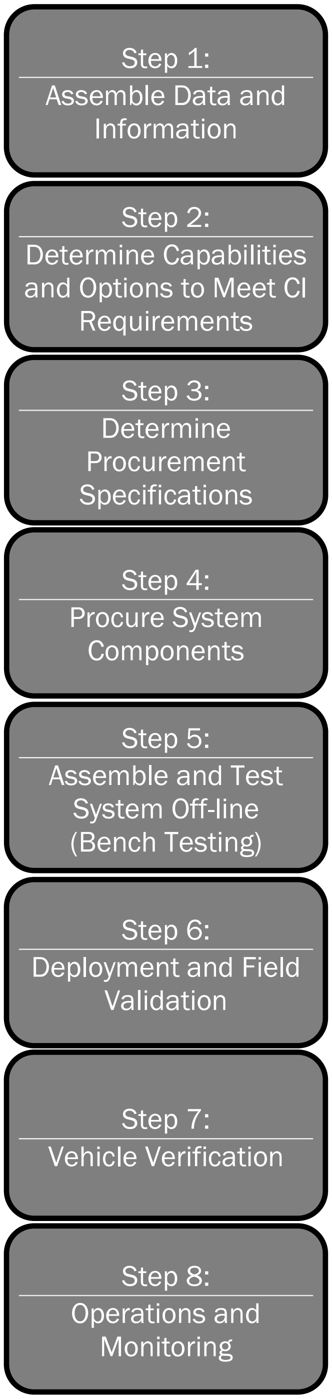
- *Connected Vehicle Pooled Fund Study MAP Guidance*[4]. Provides guidance on the creation of MAP messages to be used with corresponding SPaT messages in a connected intersection.

- *National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) 1202 v03A*[5]. Standardizes data elements for use with Actuated Signal Controller Units, such that a management station may interface with a field device to control and monitor traffic signal controllers and associated detectors.

Given the evolving nature of CIs, it is important to check online for updates to this document to ensure that the latest versions are being used.

[4] Available at: https://engineering.virginia.edu/cv-pfs-resources#accordion688161
[5] Available at: https://www.ntcip.org/file/2019/07/NTCIP-1202v0328A.pdf

2. Connected Intersection Guidance



Based on the research and activities conducted within this project, a series of eight steps were identified as common when deploying CIs. Once intersections are selected for deployment, the eight steps for each intersection are as follows:

- Step 1: Assemble Data and Information
- Step 2: Determine Capabilities and Options to Meet CI Requirements
- Step 3: Determine Procurement Specifications
- Step 4: Procure System Components
- Step 5: Assemble and Test System Off-line (Bench Testing)
- Step 6: Deployment and Field Validation
- Step 7: Vehicle Verification
- Step 8: Operations and Monitoring

The guidance included in this chapter is organized according to these eight steps that first includes a brief statement of the element or topic and then the following is provided:

- Guidance
  Includes clear statements describing the guidance and includes supporting graphics or illustrations as needed.
- Basis
  Provides supporting rationale describing why the guidance was decided and provides references to standards or examples of industry approaches.

Table 1 provides a listing of the guidance that is described in this section for each of the eight steps.

It is important to note that practitioners may prefer to customize this process by consolidating or expanding these eight steps. However, the guidance and process described in all eight steps generally apply to anyone deploying a CI with the intent to be compliant with existing standards and function with production vehicles. Another key decision that an agency deploying CIs will need to make is what applications the CI will support. The guidance does not address this decision, except by mentioning the need to consider applications in Step 2.2.

Table 1. Listing of Connected Intersections Guidance by Deployment Step

Step 1 – Assemble Data and Information	
Guidance #1.1	Inventory Signal Control Equipment
Guidance #1.2	Understand Intersection Movement Control Types
Guidance #1.3	Assess Network Readiness
Guidance #1.4	Understand Options for Storing MAP Messages
Guidance #1.5	Document Advanced Traffic Management System (ATMS) Capabilities
Guidance #1.6	Understand Position Correction Options
Guidance #1.7	Understand Intersection Makeup
Guidance #1.8	Understand Capabilities to Support Testing and Verification
Guidance #1.9	Research Federal Communications Commission (FCC) Licensing Process
Step 2 – Determine Capabilities and Options to Meet CI Requirements	
Guidance #2.1	Assess Signal Controller Readiness
Guidance #2.2	Explore External Control Local Application Needs and Capabilities
Guidance #2.3	Understand Needed Roadside Unit Capabilities
Guidance #2.4	Assess if Agency Owned Roadside Units Meet Needs
Guidance #2.5	Explore Capabilities of Other Roadside Unit Manufacturers
Guidance #2.6	Understand the Security Credential Management System
Guidance #2.7	Assess Capabilities of Staff and Contractors
Guidance #2.8	Understand Capabilities Needed to Support Remote Management
Guidance #2.9	Develop High Level Connected Intersection Design
Step 3 – Determine Procurement Specifications	
Guidance #3.1	Determine Signal Controller Procurement Specifications
Guidance #3.2	Determine External Control Local Application Procurement Specification
Guidance #3.3	Determine Roadside Unit Procurement Specification
Guidance #3.4	Determine MAP Message Procurement or Development
Guidance #3.5	Determine Radio Technical Commission for Maritime Services Procurement Specification
Guidance #3.6	Determine Security Credential Management System Procurement Specification
Guidance #3.7	Determine Test Equipment Procurement Specification
Guidance #3.8	Determine Field Installation Plans and Specifications
Step 4 –Procure System Components	
Guidance #4.1	Consider Scalability to Expand Network of Connected Intersections
Guidance #4.2	Consider Upward Compatibility to Evolving Specifications
Guidance #4.3	Consider Scheduling
Guidance #4.4	Follow Agency Practices to Procure Equipment and Services
Step 5 – Assemble and Test System Off-Line (Bench Testing)	
Guidance #5.1	Download and Familiarize with Resources to Support Off-line (Bench) Testing
Guidance #5.2	Develop Local Approach to Off-line (Bench) Testing
Guidance #5.3	Assemble and Configure the Off-line (Bench) Test Environment
Guidance #5.4	Collect Data for Off-line (Bench) Test
Guidance #5.5	Analyze Off-line (Bench) Test Data
Step 6 – Deployment and Field Validation	
Guidance #6.1	Install Equipment in the Field

2.1 STEP 1 – ASSEMBLE DATA AND INFORMATION

Step 1:
Assemble Data and Information

The CI deployment process can proceed faster when all the needed information is readily available. Later steps in determining the design and procurement for a CI will require information and/or input from multiple offices or groups within a transportation agency. This step is focused on preparation to enable CI deployers to better understand existing conditions at the intersection.

2.1.1 Objective

The objective of Step 1 is to assemble the information and knowledge of the intersection that will be needed in later steps. This includes making any early decisions about the readiness of the intersection that may be needed as input to the system design and procurement. The information assembled in this step will be documentation to be used in later steps, such as completed questionnaires, checklists, or summaries.

2.1.2 Step 1 Guidance

CI deployers are encouraged to assemble the following data and information noted in Table 2 below during Step 1 to support later steps of the CI deployment process. While this guidance encompasses the requirements specified by the *CTI 4501 v01.01 CI Implementation Guide*, CI deployers should consider local constraints, existing conditions and equipment, and the specific goals of the CI deployment, including any additional local applications or requirements that may be desired (e.g., transit signal priority).

Table 2. Step 1 - Assemble Data and Information: Guidance List

Guidance #1.1	Inventory Signal Control Equipment
Guidance #1.2	Understand Intersection Movement Control Types
Guidance #1.3	Assess Network Readiness
Guidance #1.4	Understand Options for Storing MAP Messages
Guidance #1.5	Document Advanced Traffic Management System (ATMS) Capabilities
Guidance #1.6	Understand Position Correction Options
Guidance #1.7	Understand Intersection Makeup
Guidance #1.8	Understand Capabilities to Support Testing and Verification
Guidance #1.9	Research Federal Communications Commission (FCC) Licensing Process

2.1.2.1 Step 1 – Guidance #1.1: Inventory Signal Control Equipment

Overview:

The signal control related equipment at the intersection includes the cabinet, signal controller, and controller software. During Step 1, it is important to gather as much information about these as possible to assist further decisions in later steps. Depending upon the equipment at the intersection, it may not be possible to establish a CI without replacing some or all of the equipment and this might be determined in Step 1.

There is also a need to provide power to the ECLA, if planned to be used, and the RSU, as well as an ability to perform remote management to the RSU (e.g., cycling RSU power during a disruption that renders the broadcast SPaT messages inaccurate, uploading updated SCMS certificates, uploading new MAP messages for broadcast).

Guidance:

- Work with the agency signals group to understand the cabinet type (e.g., National Electrical Manufacturers Association (NEMA) TS-1, NEMA TS-2 Type 1, NEMA TS-2 Type 2, Intelligent Transportation System (ITS) Cabinet, Advanced Traffic Controller (ATC) Cabinet, Caltrans signal controller cabinet specifications). Note that if the signal controller cabinet is a NEMA TS-1 cabinet, it will almost certainly need to be replaced before supporting this CI.
- Work with agency signals group to understand:
  - The time source for the signal controller, as well as any additional time sources used by systems at the intersection and the frequency at which it is corrected to account for drift Specifically, is the correction for drift adjusted at regular time periods or based on the extent of drift?
  - Any available space in the cabinet for additional servers or other devices;
  - Any servers already in the controller that may be used to house software added as part of the CI;
  - The signal controller brand, model, firmware version, and any capabilities as described by specifications or documentation provided by the manufacturer; and
  - The contact details of the primary contact with the signal control manufacturer representative and or local distributor.
- Prepare a brief summary of the signal control equipment *Documentation 1.1 Summary of Signal Control Equipment* for sharing during later procurement and deployment steps (see example below).

Basis:

Required to support guidance advice to come in Step 3.

Documentation 1.1 Summary of Signal Control Equipment

Intersection ID:______ Name of cross streets:________________________ Date:__________

1. Time source for the controller is _______________
2. Is the signal controller time reporting local time? Coordinated Universal Time (UTC) time? Other? _______________________
3. How frequently is the signal controller time corrected to account for drift? _______________
4. Are there any additional servers or devices at the intersection? ____
   If so, what are the time sources of these servers? _______________
5. Please indicate if there is additional space in the controller cabinet and, if so, approximate space for additional items ____
6. Please describe available power supplies and access at the intersection
   ____
7. Are there any existing servers in the cabinet that may be used to locate software to support the connected intersection? ______________
8. Please describe the signal controller brand, model, and any capabilities described in the specifications (attach a PDF of specifications if possible) _________________________________
9. Please identify the representative name and contact information that can be contacted for additional information on the intersection____

Save this completed documentation for use in procurement in Step 3.

2.1.2.2 Step 1 – Guidance #1.2: Understand Intersection Movement Control Types

Overview:

There are some movement controls that will impact the procurement and/or deployment of the CI. For example:

- If there are any protected/permissive turns during any of the timing plans, this may require additional processing if the NTCIP 1202v03A data elements are used to communicate the SPaT data. As of October 2022, there is an NTCIP working group addressing this issue and the plan is for NTCIP 1202 to eventually fully support (i.e., not require additional processing) protected/permissive turn indications. Until this is implemented, intersections with protected/permissive turns will require additional processes if using NTCIP 1202v03A to communicate SPaT data. Note that protected turns and permissive turns do not require additional processing, it is only the combination of protective/permissive that do.
- If there are any lanes that are different at different times, commonly referred to as “revocable lanes” (i.e., left-turns not permissible during peak periods, reversible lanes, lanes that restrict

certain vehicle types during portions of the day, lanes where parking is/is not allowed part of the day), it is important to note this and include this when procuring systems during later steps. Both the SPaT message and MAP messages need to be coordinated in handling of revocable lanes. In situations where there are revocable lanes, there will be a need to ensure compatibility between the SPaT and MAP messages broadcast, and this will need to be assessed during testing and verification.

- Next phase following the protected/permissive state. Meaning that any protected/permissive phases transition consistently to a next known phase. For example, it is important to understand if:
  - A Flashing Yellow Arrow (FYA) always transitions to a solid Yellow Arrow (YA) then to a Red Arrow (RA), then eventually to Green Arrow (GA); or
  - Does a FYA sometimes transition to a GA?

It is important to identify if these movement types exist and to include information about them in both the procurement step and the testing and verification steps.

<u>Guidance</u>:

- Examine signal timing plans for the intersection and any supplemental traffic signs that may restrict vehicle movements. determine if there are any Protected/Permissive turns during any timing plans.
- Complete the following Questionnaire documenting what is learned about the intersection *(Documentation 1.2 Intersection Movement Controls Questionnaire)*.
- Save the completed questionnaire as an input to future procurement tasks.

<u>Basis</u>:

> ! Note that this guidance step will need to be updated as NTCIP 1202v03A is updated, balloted, and products are available to support it.

- Understanding of current NTCIP 1202v03A.
- SAE J2735 SPaT & MAP messages – handling of revocable lanes.

Documentation 1.2 Intersection Movement Controls Questionnaire

Intersection ID:______ Name of cross streets:__________________________ Date:__________

1. Please indicate which movement controls are included in signal timing plans for this intersection:
   - ❑ Protected/Permissive turns
   - ❑ Protected turns
   - ❑ None of the above
2. Please indicate if any of the following exist at this intersection:
   - ❑ Lanes that reverse direction by time of day
   - ❑ Allowed movements (e.g., left-turn, right turn) that are not allowed at times of the day
   - ❑ Vehicle lane restrictions that vary by time of day (e.g., no trucks allowed a portion of the time, parking not allowed during limited time periods)
   - ❑ None of the above
3. Describe all possible phase transitions involving flashing arrows
   - ❑ FYA => YA => RA => GA
   - ❑ FYA => GA

Save this completed documentation for use in procurement in Step 3.

2.1.2.3 Step 1 – Guidance #1.3: Assess Network Readiness

Overview:

The CI will require secure local data communications between devices and access to the Internet (either directly from intersection or via the secure local network) to perform various actions. Some examples include:

- The security credentialling will require Internet connectivity (i.e., Internet Protocol version 6 (IPv6)) from the RSU (and possibly other devices) to connect to the security provider.
- Agency staff, vendors, or contractors supporting the CI deployment, testing and verification, or operations may require remote access to devices (ECLA, RSU, MAP server) through the secure local network to upload files, perform firmware/software updates.
- The components of the CI (RSU, ECLA, signal controller, MAP server, RTCM source) will require secure local network connections to exchange messages and/or data elements.
- The secure local network will require firewall protection to prevent outside unwanted attacks.

Guidance:

- Work with the agency signal control group, Information Technology (IT) Group, and/or ATMS managers to complete *Documentation 1.3 Network Readiness Checklist.*
- If any of the items on the checklist are not available/possible at the intersection, begin the process to establish the network functionality.

Basis:

- Requirement of SCMS.
- *CTI 4501 v01.01 CI Implementation Guide*.

Documentation 1.3 Required Network Functionality Readiness

Intersection ID:______ Name of cross streets:________________________________
Date:___________

1. Are either of the following available: a) Internet connectivity to the intersection, or b) Indirect Internet access via an internal (i.e., IOO) network that remotely connects to allowed Internet uniform resource locators (URLs)?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

2. Is a secure local network connection available at the intersection as an option for connecting an RSU, ECLA, signal controller, and additional servers, as needed?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

3. Is a firewall available that protects the local network?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

4. Is an Internal Network available at the intersection to support a secure transport protocol with mutual authentication (i.e., Transport Layer Security (TLS) or Datagram Transport Layer Security (DTLS) with client certificates)?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

5. Is remote connectivity to the local network available for authorized contractors, vendors, and/or TMS data communications?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

Save this completed documentation for use in procurement in Step 3.

2.1.2.4 Step 1 – Guidance #1.4: Understand Options for Storing MAP Messages

Overview:

The MAP message is a message created periodically and supplied to the RSU for broadcast. Unlike the SPaT data that is dynamically generated at a high frequency, the MAP message is relatively static and unchanged unless there is a change to the intersection geometry or signal groups. Nonetheless, the MAP message must reside somewhere where it can be uploaded remotely by agency staff. The *CTI*

4501 v01.01 CI Implementation Guide uses the term "MAP Server" to indicate where the MAP message is stored. This may be one of several options:

- MAP message is stored at the RSU (in this case the RSU is also the MAP Server and the RSU would perform "store and forward" broadcasting of the MAP message). The individuals who create the MAP messages would manage copies of the MAP message for them to edit or copy additional versions to the RSU, as needed.

- MAP message is stored on the ECLA (note that the ECLA itself may be a separate hardware device or may be a part of the signal controller or other device). In this situation, an automated or manual process would move a copy of the MAP message to the RSU, either once for the RSU to store and repeat broadcast of the MAP message or each time the MAP message is broadcast (although no examples of this approach have been observed in operation).

- MAP message is stored on a central server (not physically at the intersection but accessible through network connections) that allows for manual or automated processes to move a copy of the MAP message to the RSU when needed. This central server may store multiple MAP messages for different intersections.

- There may be a designated server at the intersection for the purpose of storing the MAP message.

The local deployment will eventually define where the MAP message is signed with security certificates. This may occur at the RSU, but only if the connection is secure between a MAP server and the RSU. The MAP message signature may also be applied at a MAP Server to store and periodically forward to the RSU for immediate forward.

<u>Guidance</u>:

- Work with the others in the agency to understand the existence of any MAP servers and/or the accepted or preferred approach for storing MAP messages.

- Answer the questions in the attached MAP Server Questionnaire.

<u>Basis</u>:

- Assembling this information will support activities in Steps 2 and 3.

- A MAP server may already be available or agency approach to MAP storage previously defined.

Documentation 1.4 MAP Message Storage Options Questionnaire

Intersection ID:______ Name of cross streets:_________________________ Date:__________

1. Is your agency approach to locate the MAP Message at the RSU (and apply SCMS signatures at the RSU)?
   - ❑ Yes
   - ❑ No, or no current policy

   Note: If Yes, you do not need to complete the remainder of the questionnaire.

2. Does your agency have a central MAP server where you will locate the MAP message for this intersection?
   - ❑ Yes
   - ❑ No

   Note: If Yes, you do not need to complete the remainder of the questionnaire.

3. Are there any other preferences for locating the MAP server:
   - ❑ Locate MAP server on the ECLA
   - ❑ Deploy a separate server to house the MAP message
   - ❑ We have no preference

Save this completed documentation for use in procurement in Step 3.

2.1.2.5 Step 1 – Guidance #1.5: Document Advanced Traffic Management System (ATMS) Capabilities

Overview:

Agencies operating an ATMS may have established operational software capable of sending files and communicating with devices connected to the ATMS. This may support the functionality of CIs in several ways:

- The ATMS could support the communication of MAP messages to the RSU or MAP Server.
- The ATMS could allow for software or firmware upgrades to the RSU.
- The ATMS could support communication of RTCM messages.
- The ATMS could support remote management functions and control power to the RSU.
- The ATMS could be used to program updated SPaT information to the signal controller (e.g., to include the status of revocable lanes in the MAP message).

There have been situations where there are compatibility issues between the ATMS and RSUs, therefore compatibility testing needs to be conducted in advance of launching the intersection.

Understanding the connections and capabilities of the ATMS as well as any compatibility issues will support later design decisions.

<u>Guidance</u>:

- Work with your agency signal control group and/or transportation management center (TMC) to understand the ability to perform remote connections to devices and systems (e.g., to install firmware or software upgrades to the RSU) from remote locations.
- Work with the agency signal control group to determine if the MAP server could be located at the ATMS and provide MAP files to the RSU remotely.
- Contact the ATMS vendor (or in-house ATMS software developer) and ask about any experiences communicating between the ATMS and RSUs in other deployments.
- Complete *Documentation 1.5 ATMS Questionnaire* to document the findings of research in Step 1.5.

<u>Basis</u>:

- Assembling this information will support activities in Step 3.

Documentation 1.5 ATMS Questionnaire

Intersection ID:______ Name of cross streets:________________________________ Date:__________

1. Is there an ATMS system in-place with established communications to this intersection?
   - ❑ Yes
   - ❑ No

   Note: If No, please describe any capabilities to perform remote control or send/receive files with the signal controller or other servers in the signal cabinet:____

2. If Question #1 is yes, describe the ATMS vendor/support
   - ❑ Developed and supported in house
   - ❑ Purchased and supported by a vendor. Vendor is ________________________

3. If Question #1 is yes, can the ATMS support the following activities?
   - ❑ Communicating MAP messages to the RSU or MAP Server
   - ❑ Allowing software or firmware upgrades to the RSU
   - ❑ Communication of RTCM messages
   - ❑ Remote management functions and control of power to the RSU
   - ❑ Programming updated SPaT information to the signal controller (e.g., revocable lanes)

4. When you contacted the ATMS vendor/support, did they indicate whether their system has been integrated with any RSUs:
   - ❑ Yes, successfully integrated with the following RSU brands
   - ❑ Yes, and noted compatibility issues summarized as ____ (include RSU vendor with any issues)
   - ❑ They have not had experience integrating with RSUs

Save this completed documentation for use in procurement in Step 3.

2.1.2.6 Step 1 – Guidance #1.6: Understand Position Correction Options

Overview:

The RTCM Corrections message is a required component for IOOs planning to deploy CIs. The two options for providing the RTCM message are:

1. Deployment of a real-time kinematic (RTK) base station at or near the intersection (*CTI 4501 v01.01 CI Implementation Guide* recommends base stations should be within 25 miles of the intersection, and one base station may provide RTCM messages for multiple intersections).

2. RTCM data and/or messages may be obtained from the network via Internet Protocol (NTRIP), from a Continuously Operating Reference Station (CORS), or from other sources of positioning corrections.

The RTCM messages will need security credentials attached to the messages, and the preferred approach is that the RTCM security credentials be added at the location where the RTCM message is created.

Guidance:

Agency staff should familiarize themselves with the concept of RTCM messages supporting position correction by reviewing the CV PFS Technical Topic Summary titled Radio Technical Commission for Maritime Services (RTCM) Corrections Message.

- Agency staff should familiarize themselves with the requirements in the *CTI 4501 v01.01 CI Implementation Guide* related to RTCM, and download the NRTM, highlighting all requirements related to RTCM (save as *Documentation 1.6a CI NRTM for RTCM).*

- Because the *CTI 4501 v01.01 CI Implementation Guide* references the SAE J2735_202007 standard as the source for minimum data elements, agency staff should also review this standard.

- Using the knowledge of RTCM gained from these resources, agency staff should familiarize themselves with RTCM alternatives to understand what options are available and the associated costs. For example:

  - The state, city, or county may have access to CORS data supplies for RTCM data;

  - Commercially available CORS data may be available in the area on a subscription basis; and

  - The agency approach might be to deploy RTK base stations near the CIs.

- If existing base stations are available as possible sources of the RTCM messages, gather information about the location of the base and attempt to find stations within 25 miles of the CI.

- Complete the attached *Documentation 1.6 CORS/RTCM Questionnaire* and save for use in Steps 3-4.

Basis:

- Understanding these options may reduce costs or acquiring position correction data and will support selection of position correction approach.

Documentation 1.6 CORS/RTCM Questionnaire

Intersection ID:______ Name of cross streets:_________________________ Date:__________

1. Are you aware of a statewide or local CORS network/system that offers position correction data? (note: CORS operations may be partnerships between state DOTs and local counties, cities and private companies. We recommend checking with your surveying or land management groups to explore the availability of CORS).
   - ❑ Yes
   - ❑ No, we do not have access to a public operated CORS
   - ❑ Unknown

   Note: If Yes, you do not need to complete the remainder of the questionnaire.

2. If Question 1 is "yes", does the coverage of your CORS include the location of the intersection? (note: you may find this information from either locations of base stations supporting CORS data (base stations should be within 25 miles of the intersection, or from CORS coverage maps indicating geographic area covered by the network of stations).
   - ❑ Yes
   - ❑ No

   Note: if Question 2 is No, you do not need to complete the remainder of the questionnaire.

3. Research if there are any connected intersections (operated by your agency or partner agencies (e.g., local cities or counties) that are within 25 miles of this intersection. Share the *CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide* with the CORS support team, requesting them to review the RTCM requirements in the NRTM table (2.4.3.1.1 "Uniform" section) – Note: the *CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide* references the SAE J2735_202007 standard, therefore this will need to be shared with the CORS support team.
   - ❑ Our CORS support team has reviewed the standards and determined CORS is able to supply the RTCM formatted messages
   - ❑ Our CORS support team has reviewed the standards and determined CORS is <u>NOT</u> able to supply the RTCM formatted messages
   - ❑ We are still researching

Save this completed documentation for use in decisions about RTCM in Step 3.

2.1.2.7 Step 1 – Guidance #1.7: Understand Intersection Makeup

<u>Overview</u>:

Guidance 1.1 suggests researching and understanding the physical makeup of the intersection (including space and power availability) to determine if there are any issues that may prevent the successful deployment of the CI. In Step 1.7, agencies are encouraged to review RSU mounting options and the line of sight that RSUs installed at the intersection are likely to have, including any man-made or natural objects (e.g., vegetation) that may limit line of sight.

The CI will require an RSU mounted with line-of-sight access to vehicle travel lanes into and out of the intersection. The RSU will need local network connection to the signal controller and therefore should be in close proximity to the signal controller to allow this connection with minimal cable lengths.

Guidance in later steps will consider the physical makeup of the intersection. Therefore, in Step 1, IOOs should gather the information and create an understanding of the physical makeup of the intersection.

<u>Guidance</u>:

- Agency staff should familiarize themselves with available options for mounting RSUs. Typically, RSUs are mounted on the signal control mast arm or other support structure at the controller and connected by local network wiring to the signal controller.
- Agency staff should conduct a visual line-of-sight survey to understand if any vegetation or physical objects (e.g., bridges, poles, signs, etc.) may obstruct the communications from the RSU to the vehicles.
- Complete the attached Physical Infrastructure Makeup Questionnaire. This questionnaire will be useful if an integrator is procured during Step 3.

<u>Basis</u>:

- Assembling this information will support activities in Step 3.

Documentation 1.7 Physical Infrastructure Makeup Questionnaire

Intersection ID:______ Name of cross streets:__________________________ Date:___________

1. Have you identified a mounting location for the RSU?
   - ❑ Yes. Please describe the location (e.g., southwest corner mast arm) insert pictures if possible
   - ❑ No
2. Have you assessed local connections from the proposed RSU site to the signal controller?
   - ❑ Yes, a local power over ethernet cable connection can be established between the signal controller and RSU
   - ❑ No, unknown
3. Have you completed a visual line of sight survey for this location?
   - ❑ Yes, no obstructions were noted
   - ❑ Yes, the following obstructions may pose issues to the RSU _________________________

Save this completed questionnaire as it may be used in procurement in later steps.

2.1.2.8 Step 1 – Guidance #1.8: Understand Capabilities to Support Testing and Verification

Overview:

Testing, validation, and verification of the CI will be needed before obtaining security credentials that are used by OEM production vehicles. These testing, validation, and verification processes are rigorous and require access to data from the signal controller to conduct the detailed analysis to determine if the SPaT data is accurate and complete.

In order to test and verify the accuracy and completeness of the SPaT data at this intersection, the group(s) performing the testing will need adequate access to sufficient data. Specifically, it will be important to assess the following:

- Message content (e.g., does the SPaT message accurately describe the current signal displays and end times of current intervals?).
- Message latency.
- Message frequency (i.e., in-vehicle applications rely on receiving messages every $1/10^{th}$ second).

For signal systems that utilize Automated Traffic Signal Performance Measures (ATSPM) data reporting, the ATSPM data may be compared with captured SPaT data to confirm SPaT accuracy. Another approach for testing can be to connect a tool (e.g., Wireshark) to an output port of the TSC to collect output data. Packet Capture (PCAP) data files are another example of data files used to capture and exchange data. Each agency deploying a CI should plan for how data will be captured to support the testing and verification process because it may impact deployment and should not be an afterthought left unaddressed until ready to perform testing.

Guidance:

- Complete the Documentation 1.8 Checklist of Testing & Verification Capabilities. The items in the checklist will be needed in later phases of CI testing and validation.

- If any required item is not met, it should be identified as a shortcoming. Later steps for procurement will need to include specifications to upgrade existing equipment or deploy additional hardware or software to meet the requirement.

Basis:

- SPaT data must be readily available for access by authorized users via a mechanism for testing and verification of the availability and accuracy of the SPaT data delivered to the RSU and broadcast by the RSU.
- Published standards (e.g., SAE J2735, *CTI 4501 v01.01 CI Implementation Guide*) describe requirements for testing and verification.

Documentation 1.8 Testing and Verification Capabilities Checklist

Intersection ID:______ Name of cross streets:___________________________ Date:___________

1. Is yellow phase end time data captured by the signal controller (or other data collection methods) available to support yellow phase interval duration analysis? (The onset of the yellow phase will be included in the SPaT message and therefore must represent an accurate time for when the yellow phase will end; it is not possible to observe this in the field.)
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

2. Can an output of signal controller phase onsets be logged and made available to compare with logged OBU data captures during testing and validation? (The time that SPaT messages are received by OBUs will be compared to the actual time of interval onset for the yellow and red phases. A test procedure is defined for conducting this using video capture of signal head change compared to OBU display. However, this log is necessary if the site wishes to conduct an additional, post analysis.)
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

3. Are all systems set to UTC time and drift minimized, in order to support testing at later stages? (The standards and supporting data exchanges for SPaT information use time "ticks" or countdowns or remaining seconds until interval changes. This addresses challenges of synchronicity issues between signal controllers, RSUs, and OBUs. However, to test and validate the time differences between interval changes, it is important to have time clocks synchronized, otherwise post testing analysis of the data is not possible.)
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

Save this completed documentation for use in procurement in Step 3.

2.1.2.9 Step 1 – Guidance #1.9: Research Federal Communications Commission (FCC) Licensing Process

Overview:

Each CI will require an FCC license for the broadcast of data by the RSU. The FCC licensing process requires several steps, some that can be performed during the planning phase of the CI and some that cannot be completed until specific information is known about the intersection. Many DOTs may have staff who already work with the FCC for their department's radio communications. These staff may be helpful in understanding and advancing the FCC licensing process for CIs. Additionally, AASHTO provides frequency coordination support by the AASHTO Committee on Transportation System

Operations Communications Technology. More details can be found on the AASHTO website at: https://frequencycoordination.transportation.org/.

Activities that can be done during the CI planning phase:

- Familiarizing with the FCC RSU licensing process.
- Obtaining an FCC Registration Number (FRN) or understanding if the agency already has an FRN.

Searching to understand if the targeted spectrum is vacant and available in the location of the CI. The website to search for licenses can be found at: https://wireless2.fcc.gov/UlsApp/UlsSearch/searchLicense.jsp.

Filing the FCC application requires the following information that will not be known until closer to the deployment of the CI:

- Latitude/Longitude of the fixed RSU antenna.
- Fixed RSU antenna height.
- Manufacturer of the RSU antenna.

Guidance:

- Explore whether your agency has staff that work with the FCC on licensing and whether these staff may be able to support the CI licensing process.
- Explore the services offered by AASHTO, as referenced above.
- Review available resources to understand the FCC licensing process. Note: The FCC plans to sunset the use of DSRC, and final licensing rules for C-V2X are still pending. Examples of licensing resources available at the time this Guidance Document was published are listed below, but agencies should check for more recent resources. Some examples include:
    - Recommended Practices for DSRC Licensing and Spectrum Management. This Federal Highway Administration (FHWA) document (developed by the Intelligent Transportation Society of America (ITS America)) is specific to Dedicated Short-Range Communications (DSRC) licensing, but also includes considerable background information into the overall process of FCC licensing, as current in 2015.
    - Cellular-V2X (C-V2X) Experimental Licensing User Guide. This document was developed by Qualcomm and described the process for experimental C-V2X license applications.

- Wireless Telecommunications Bureau and Public Safety and Homeland Security Bureau Provide Guidance for Waiver Process to Permit Intelligent Transportation System Licensees to Use C-V2X Technology in the 5.895-5.925 GHz Band. This is an FCC document that provides guidance to ITS licensees seeking waivers to operate RSUs with C-V2X broadcasts prior to FCC adopting final rules.

Basis:

- FCC licenses are required for each CI, and the FCC process should be understood to prepare an approach.

2.1.3 Summary and Outcomes of Step 1

Upon completing Step 1, practitioners should have a better understanding of the existing conditions and options regarding agency systems and equipment at the intersection. The information assembled in this step should include documentation that will be used in later steps, as detailed in Table 3.

Table 3. Documentation Developed in Step 1 for Use in Later Steps

Documentation	Developed as Part of...	For Use in...
Intersection Movement Controls Questionnaire	Guidance #1.1	Guidance #3.1
Summary of Signal Control Equipment	Guidance #1.2	Guidance #3.1
Completed Network Readiness Checklist	Guidance #1.3	Guidance #3.1 and Guidance #3.2
Completed MAP Server Questionnaire	Guidance #1.4	Guidance #3.2
Completed ATMS Questionnaire	Guidance #1.5	Guidance #2.8, Guidance #3.1, and Guidance #3.2
CI NRTM for RTCM	Guidance #1.6	Guidance #3.5
Completed CORS/RTCM Questionnaire	Guidance #1.6	Guidance #3.5
Physical Infrastructure Makeup Questionnaire	Guidance #1.7	Guidance #3.1
Completed Testing & Verification Capabilities Checklist	Guidance #1.8	Guidance #3.1

2.2 STEP 2 – DETERMINE CAPABILITIES AND OPTIONS TO MEET CI REQUIREMENTS

Step 2:
Determine Capabilities and Options to Meet CI Requirements

This step continues to assemble information to support the design and procurement for a CI. In contrast to Step 1 that focused on existing intersection conditions, this step introduces the reader to CI requirements in order to help assess what upgrades or additional equipment will be needed to deploy a CI.

This step is based on CI requirements contained within the *CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide*, which was developed by the Institute of Transportation Engineers (ITE) and its partner organizations including USDOT, SAE, NEMA, and the American Association of State Highway and Transportation Officials (AASHTO). It is recommended that practitioners visit the ITE CTI family of standards website to ensure that they are using the latest version available.

2.2.1 Objective

The objective of Step 2 is to understand and compare CI requirements with the capabilities of existing systems and options that are available to the deployer for enhancements or additions. Step 2 will help practitioners prepare to procure upgrades to existing equipment and/or new equipment in the later steps.

2.2.2 Step 2 Guidance

CI deployers are encouraged to determine the capabilities and options identified in Table 4 below during Step 2 to support later steps of the CI deployment process.

Table 4. Step 2 – Determine Capabilities and Options to Meet CI Requirements: Guidance List

Step 2 – Determine Capabilities and Options to Meet CI Requirements	Guidance #2.1	Assess Signal Controller Readiness
	Guidance #2.2	Explore External Control Local Application Needs and Capabilities
	Guidance #2.3	Understand Needed Roadside Unit Capabilities
	Guidance #2.4	Assess if Agency Owned Roadside Units Meet Needs
	Guidance #2.5	Explore Capabilities of Other Roadside Unit Manufacturers
	Guidance #2.6	Understand the Security Credential Management System
	Guidance #2.7	Assess Capabilities of Staff and Contractors
	Guidance #2.8	Understand Capabilities Needed to Support Remote Management
	Guidance #2.9	Develop High Level Connected Intersection Design

2.2.2.1 Step 2 – Guidance #2.1: Assess Signal Controller Readiness

Overview:

During Step 3 of this process, you will be creating procurement specifications to acquire any needed upgrades to the signal controller. In addition to, or in lieu of, updating the signal controller, you may also procure a vendor or contractor to develop functionality in an ECLA. Finally, you may need to replace the signal controller if upgrades to support CI functionality are not possible. The first step towards developing these specifications is to understand the extent to which the current signal controller meets the CI requirements. Some combination of the following four scenarios is likely the situation of your signal controller:

- *Meets CI requirements.* All the CI requirements are met by your signal controller and your controller is ready to communicate accurate and complete SPaT data to the RSU as per the CI requirements. In 2022, it is unlikely that your signal controller meets all the CI requirements, but this is expected to become increasingly possible in future years.

- *Can meet CI requirements with available product upgrades.* Some of the CI requirements are not met by your signal controller, but the manufacturer has commercially available product upgrades for your controller that could meet some or all the requirements.

- *Can meet CI requirements with ECLA.* The signal controller alone does not meet all the CI requirements, but with additional functions performed by add-on software and/or hardware modules, all CI requirements can be met without replacing your current signal controller. The CV PFS developed Multi-Modal Intelligent Traffic Signal System (MMITSS) software is an example of this.

- *Cannot meet CI requirements.* The functions of your signal controller are such that even with upgrades and/or an ECLA it is not possible to meet the CI requirements and a new signal controller and possibly a new cabinet will be required to deploy a CI that meets all requirements.

The *CTI 4501 v01.01 CI Implementation Guide* provides details about signal controller requirements to satisfy basic data needs for RLVW applications. Specifically, the Needs to Requirements Traceability Matrix (NRTM) identifies the requirements that are mandatory, conditional, or optional, and the NRTM is intended to be used by procurement personnel to specify the required functionality in the CIs to support RLVW.

The NRTM includes a detailed introduction that describes how the matrix is organized by User Need Identification (ID) in Column 1 and User Needs in Column 2. All the requirements and relation to each user need are identified in the requirement ID (Column 3) and requirement (Column 4). The requirements for SPaT data generation and communication to the RSU are included in various locations within the NRTM as they are related to different user needs. Many requirements in the NRTM relate to MAP or RTCM messages or relate to security and testing and likely will not be addressed by the signal control manufacturer when they complete the matrix. The following are user need IDs and user needs related to key requirement of the *CTI 4501 v01.01 CI Implementation Guide* NRTM that agencies should ensure the signal control manufacture addresses:

- 2.4.2.1 Provide Signal Timing Data to an RSU – all requirements.
- 2.4.2.2 Provide Signal Timing Status to an RSU – all sub requirements.
- 2.4.3.2 Generic Message Data Needs – all SPaT related requirements.
- 2.4.3.3 Signal Timing Data Needs – all sub needs.
- 3.3.2 TSC Infrastructure to RSU Requirements – including all sub requirements.
- 3.3.3 Message Requirements – all sub requirements starting in “SPaT Message”.

RLVW Support User Needs

Section 2.4.2.3 of the CTI 4501v1.01 CI Implementation Guide introduces User Need 2.4.2.3 that traces to three requirements defined to support the full functionality envisioned for RLVW. These include the provision of Assured Green End time (AGET), Assured Green Period (AGP), and Minimum End Time with AGP. Currently, there has not been a demonstrated working solution to meet these requirements consistently for all signal timing plans. Therefore, at the time this guidance was created, basic RLVW applications are being tested to all requirements except these three. It is suggested that you request your signal control manufacturer to address these, when possible.

In addition to the requirements in the NRTM, there is also a need for the signal controller to be on UTC time and to maintain UTC time with minimal drift, or for clock corrections to UTC time to be made in the messages by the ECLA or RSU. This is especially important for testing the CI in later steps.

<u>Guidance</u>:

- During Step 2, share the *CTI 4501 v01.01 CI Implementation Guide* NRTM with your current signal controller vendor and/or representative and ask them to indicate which of the Functional Requirements can be met with your current signal controller.
    - For requirements with Conditional and/or Optional conformance “Yes / No” in the Support column, ask them to comment on <u>all options as stated in the NRTM</u>. Later, the requirements with optional conformance will be clarified by you prior to any procurement of new systems.
    - Ask your manufacturer to complete the matrix as follows:

- Clearly identify which requirements are met with the existing controller today (e.g., “Meets today”).
- Clearly identify which requirements will be met with an existing firmware product upgrade (e.g., “Meets w/Upgrade”).
- Clearly identify which requirements cannot be met that will require ECLA functions (e.g., “ECLA”).
- Clearly identify which requirements are not possible even with an ECLA (e.g., “Not possible”) meaning the controller cannot provide the function to enable an ECLA to meet the requirement.
- Based upon your completion of Documentation 1.8, specifically your response to the question about the ability of your signal controller to accurately report time in UTC time with minimal drift, consider asking your vendor to clarify the ability for the signal controller to remain current to UTC time. This will be critical to later testing of the CI.

- Review the vendor’s responses, clarifying any ambiguities in their responses as this information will be critical during Step 3. It is critical to emphasize that you are asking the vendor to indicate for each requirement the current operational functionality at your controller or functionality offered by a production product they currently offer. You are not requesting to understand theoretically what is possible.
- Save the NRTM with comments from the manufacturer (and any clarifying notes) as *“Documentation 2.1 Completed Signal Controller NRTM”.*

Note: As more and more IOOs request the signal controller manufacturers to complete the NRTM, the vendors will likely be able to produce completed matrices very quickly, with only local tailoring (e.g., to adjust to local versions of controllers) needed from the general responses from the vendor.

<u>Basis</u>:

- The requirements in the NTRM form a solid basis for assessing the ability of the signal controller to support validated CIs.

2.2.2.2 Step 2 – Guidance #2.2: Explore External Control Local Application Needs and Capabilities

<u>Overview</u>:

While the simplest approach for delivering SPaT data to the RSU would be a direct connection from the Signal Controller to the RSU, there are a variety of reasons why additional software may be required between the two systems. This additional software is referred to in the *CTI 4501 v01.01 CI*

Implementation Guide as an ECLA and may require a dedicated hardware server or may be housed and operated on an existing server. After completing Guidance 2.1, the completed NRTM will give you an initial understanding of the need for and potential role of an ECLA at this intersection to support SPaT data creation and formatting, especially if the signal controller manufacturer responded with "ECLA" to some requirements.

The intent of this guidance is to encourage IOOs to understand if they may require or benefit from an ECLA and to familiarize with the capabilities and options for ECLAs that will support possible procurements later. Four examples of possible needs for ECLA are:

- *Addressing requirements not met by the signal controller.* Any requirements marked as either "meets w/upgrade" or "ECLA" in the completed NRTM in Step 2.1 are possible roles for the ECLA. Examples of these include:

  - *Real-time message conversion.* One example role of the ECLA is to convert the data that comes out of the signal controller into the SAE J2735 SPaT message before communicating it to the RSU.

  - *Supplemental data.* While the signal controller must output the real-time signal control data, there are some required data elements that could be appended by the ECLA, if they are not generated by the signal controller. The Road Regulator ID is an example of a data element that is static for the intersection and could be appended to a message output from the controller. Another example could be revocable lanes where the source implementing the revocation may be the TMC or TSC, and the ECLA may need to append the SPaT message.

- *Storing MAP Messages.* An ECLA may be the location where the MAP messages are stored and accessed by the RSU (i.e., serving as the MAP Server).

- *Testing/Troubleshooting.* There may be advantages to having the ECLA to assist in capturing data while performing the verification process or troubleshooting challenges.

- *Functions beyond message broadcast.* You may wish for this CI to perform more functions than just delivering messages to vehicles. For example, you may need to receive and process Basic Safety Messages (BSMs) from vehicles. Additionally, you may wish to process signal priority requests and adjust signal timing as part of a network signal management system. These are examples where the logic and supporting operations could be included in the ECLA.

<u>Guidance</u>:

- Gather input from others in your organization about possible applications that the CI at this location may support (e.g., signal priority, signal preemption, warning applications requiring

Traveler Information Message (TIM) or Road Safety Message (RSM) broadcasts, BSM receiving and processing).

- Review Documentation 2.1 Completed Signal Controller NRTM, recognizing that any requirements marked as either “meets w/upgrade” or “ECLA” are possible functions to be performed by the ECLA.

- Research examples of ECLAs deployed in other CIs. Example sources include:

  - *Multi-modal Intelligent Traffic Signal System (MMITSS)*. The CV PFS has developed the MMITSS software that may serve as an ECLA.

  - Utah DOT is a good example of a state that operates an ECLA that converts TSCBM messages output by the signal controller and creates the SAE J2735 SPaT messages that are communicated to the RSU. UDOT’s ECLA is a product called “Signal Command Module” manufactured by Helix Innovations.

  - *V2X Hub*. The USDOT has developed the V2X Hub, which may serve as an ECLA.

  - *Connect:ITS*. MH Corbin offers the Connect:ITS advanced roadside controller, which is used by Ohio DOT and can serve as an ECLA.

- Complete *Documentation 2.2 List of Needs for ECLA (see below)* as it will be used in Step 3 to prepare ECLA procurement specifications.

Basis:

- ECLA may be critical to the success of the CI and may help to avoid replacing or upgrading signal controllers.

- The use of an ECLA may help CIs be interoperable with multiple brands of RSUs.

Documentation 2.2 List of Needs for ECLA

Intersection ID:______ Name of cross streets:_________________________ Date:__________

Functions Beyond SPaT/MAP/RTCM Message Broadcasts:

1. Do you plan to broadcast messages to support other applications at this intersection beyond SPaT messages?
   - ❑ Yes, we are planning to broadcast TIM or RSM messages for reduced speed warning
   - ❑ Yes, we are planning to broadcast TIM or RSM for curve warning
   - ❑ Yes, we are planning to broadcast TIM or RSM for spot weather warning
   - ❑ Yes, we are planning to broadcast TIM, RSM, or Work Zone Data Exchange (WZDx) for work zone information
   - ❑ Yes, we are planning to broadcast one or more additional "other" messages that may require ECLA support.
   - ❑ No

2. Do you plan to support signal priority or preemption using the CI functionality
   - ❑ Yes, we plan to use this RSU to receive priority/preemption requests and will require functionality to process requests and generate/broadcast priority reply messages
   - ❑ No, either we are not planning signal priority/preemption, or it is already supported by existing systems and will not use the CI

3. Are you planning to receive and process BSMs from vehicles and wish to process and incorporate the data into your operations?
   - ❑ Yes
   - ❑ No

If you answered "Yes" to any of the above questions, attach additional information about your planned deployments (e.g., any preliminary project summaries or concept definitions) as they will be helpful when procuring support for the ECLA.

SPAT NRTM Related Needs for the ECLA:

During Step 2.1, you interacted with your signal control manufacturer and received a response to the NRTM which likely identified requirements they may address through product upgrades and requirements they cannot address (and recommend for the ECLA). Create a subset matrix of those requirements that you would like to receive bids/estimates on from ECLA vendors or support contractors. This may be all the requirements marked as "Meets w/upgrade" or marked "ECLA" or you may have an understanding of what requirements you will address by working with your signal control manufacturer.

Assemble your answers to Questions 1-3 (including any attached descriptions or scoping deliverables) and the NTRM identifying those requirements you believe may be addressed by the ECLA.

2.2.2.3 Step 2 – Guidance #2.3: Understand Needed Roadside Unit Capabilities

<u>Overview</u>:

A Roadside Unit (RSU), as shown in Figure 2, is the device that will broadcast SAE J2735 SPaT, MAP, and RTCM messages. However, the RSU must perform additional roles beyond broadcasting messages. The intent of this guidance is to present a high-level overview of the RSU roles and requirements and provide references to the *CTI 4001 v01 RSU Standard*, where the full requirements are documented.

Source: Siemens

Figure 2. Roadside Unit

<u>Examples</u> of the roles of the RSU include the following:

Message Handling – Forwarding Messages. The RSU will need to receive messages from up to three sources (i.e., TSC Infrastructure, MAP server, RTCM source) and broadcast the messages using SAE J2735 standards. The RSU will either perform “Immediate Forward” or “Store and repeat” forwarding of messages. Section 4.3.2.13 of the *CTI 4001 v01 RSU Standard* includes additional details on message handling. The RSU will need to perform a critical role to ensure the SAE J2735 SPaT message is broadcast within the required bounds of latency and frequency.

Message Handling – SPaT Data. The RSU will receive SPaT data from the TSC Infrastructure at a frequency of 10 Hz. This data will either be received by the RSU as SAE J2735 messages, NTCIP 1202v03A data elements, or using the Traffic Signal Controller Broadcast Message (TSCBM). If SPaT data is received as SAE J2735 messages, the RSU does not need to process or convert the data (but likely will need to attach security certificates). If the RSU receives SPaT data as either NTCIP 1202v3A or TSCBM, the RSU will need to assemble the SAE J2735 SPaT message for broadcast, attach security certificates, and may need to correct the time information in the message to UTC time. The *CTI 4001 v01 RSU Standard* describes that each RSU should be capable of supporting all three data exchange approaches, but it is not known if all RSUs do so. Feedback from your signal controller *(Documentation 2.1 Completed Signal Controller NRTM*) will help you understand if the RSU being used will need to support NTCIP 1202v03A and/or TSCBM. TSCBM currently is not able to meet the requirements of CTI 4501 without custom processing in the ECLA or RSU. No efforts are known to be underway or planned to update TSCBM. At the time this document is prepared, NTCIP 1202v3A is being updated to be able to meet the requirements of CTI 4501.

Security Certificates. Each message broadcast by the RSU will require a signed security certificate. The RSU may either receive messages that are signed by the source or may receive messages that are not signed by the source. For messages not signed by the source, the RSU will need to connect to the security provider, obtain certificates and apply these certificates to sign the message. This requires the RSU to enroll in the security provider SCMS exchange.

Hardware Security Module (HSM). RSUs need to provide physical protection to secure sensitive information using an HSM. Additional details of the HSM can be found in the *CTI 4001 v01 RSU Standard* in section 2.5.5.7.

Local Network Interface Security. Connections between the RSU and other devices on the internal network need to be secure to protect the communications. The RSU needs to support TLS 1.3. Details of the RSU interfaces can be found in the *CTI 4001 v01 RSU Standard* in section 3.3.5.1.

Message Broadcast Priority. A role of the RSU will be to prioritize the broadcast of SPaT messages, MAP messages, TIMs, and other messages to ensure minimum latency and frequency requirements for all messages are met.

Received Message Processing. The RSU will also need to receive and process messages as configured locally (e.g., some agencies may receive and process BSMs others may receive and process signal request messages (SRMs)). The receipt and processing of incoming messages will need to be performed without jeopardizing message broadcast requirements.

Message Broadcast Range. A message broadcast range of 300 to 500 meters is typically assumed to be the broadcast range achievable by RSUs. Field testing in Step 7 will test this broadcast range to determine if local landscape or obstructions are preventing this. However, these broadcast ranges should be considered when planning for and procuring RSUs.

Guidance:

- Download and review the current version of the *CTI 4001 v01 RSU Standard*, paying close attention to how the above example roles are described. Specifically review the NRTM.
- Familiarize yourself with the OmniAir RSU certification process. The OmniAir Certified Products website includes categories of products. The product category "RSU" includes all certified RSUs.
- Complete the attached *Documentation 2.3a Desired RSU Certifications and Additional Requirements.*
- Copy and save the NRTM in the *CTI 4001 v01 RSU Standard* as *Documentation 2.3b Downloaded RSU NRTM*.

Basis:

- Will provide background into the role and function of RSUs to assist in developing the high-level CI design.

Documentation 2.3a Desired RSU Certifications and Additional Requirements

Intersection ID:______ Name of cross streets:__________________________ Date:___________

1. ***Certifications.*** The following certifications have been identified as those that should be considered when assembling RSU specifications:
   - ❑ Certified RSU product category on the OmniAir website

2. ***Additional Requirements***
   - ❑ ***MAP Availability.*** The SAE J2735 SPaT Message include a status bit for "No MAP Available", that must either be indicated as the value 0 when a valid MAP message is available or as a 1 when no MAP is available. Check this box and note this functionality if you require the RSU to append the SPaT Data to indicate whether a valid MAP message is available.

3. Please list additional requirements, functions, or capabilities of the RSU beyond what is in the *CTI 4001 v01 RSU Standard* or those listed above (e.g., those you have learned from interactions with other agencies deploying connected intersections, feedback from CV PFS members, etc.).
   - ❑ _____________________
   - ❑ _____________________

Save this documentation as it may be used to support the procurement of new RSU devices in later steps.

2.2.2.4 Step 2 – Guidance #2.4: Assess if Agency Owned Roadside Units Meet Needs

Overview:

Guidance 2.3 provided background information to assist IOOs in understanding the role and requirements of the RSU. The RSU may be purchased with input from Guidance in Steps 3-4. However, it is possible that your agency already has one or more RSUs available from earlier procurements that you are considering or planning to use for this deployment. The intent of this guidance is to help you understand if your agency owned RSU meets the *CTI 4501 v01.01 CI Implementation Guide* requirements. If it does not, you will need to procure a new RSU.

If you do not have any existing RSUs, skip this guidance. If you have existing RSUs that only support DSRC broadcasts (i.e., do not support C-V2X), skip this guidance, those will not meet current and future FCC rules.

Guidance:

- When you bought the RSU, you likely received documentation, specification sheets, or users' manuals. Use these to compare with requirements identified in *Documentation 2.3b Downloaded RSU NRTM*.

- Share the NRTM with the vendor of your current RSU and ask them to indicate (i.e., check mark, initials) which of the Functional Requirements can be met with your current RSU.

- The RSU may identify OmniAir certifications. Compare any certifications noted against those in *Documentation 2.3a Desired RSU Certifications and Additional Requirements.*

- Note that, in addition to the requirements identified in Guidance 2.3, it is important to understand if your current RSU will only support the receipt of SPaT data using SAE J2735 messages or if it can successfully receive NTCIP 1202v03A and/or TSCBM messages and assemble the SAE J2735 messages. This is because if the RSU used at the intersection can only receive SAE J2735 messages, then the TSC Infrastructure will need to output the SPaT data in this format.

- Append any notes or clarifications to the completed NRTM and save it as *Documentation 2.4 Completed Owned RSU NRTM.*

- Only in situations where you have been able to confirm that all the CI requirements are met by your current RSU (either through specification review or the manufacturer completed NRTM) should you proceed with using your existing RSU. Otherwise plan to purchase an RSU using specifications created in Step 3.

Basis:

- Could help identify existing RSU and avoid the need to purchase new.

2.2.2.5 Step 2 – Guidance #2.5: Explore Capabilities of Other Roadside Unit Manufacturers

Overview:

Unless you have an RSU already for this CI, you will need to purchase an RSU, and guidance is available on developing specifications to support the procurement of RSUs in Step 3. Even if you already have an acceptable RSU, you may wish to explore the latest capabilities of RSU manufacturers as the industry is rapidly evolving and new functions and features may be available at the time you are deploying your CI.

Guidance:

- *Inquire about added RSU functionality.* The *CTI 4501 v01.01 CI Implementation Guide* (Annex A) suggests that RSU providers may eventually choose to incorporate RTCM-related functionality into the RSU. If this occurs, the source of RTCM would be much simpler. This is one example, and there may be other examples. IOOs may ask RSU providers about this and other capabilities recently added to RSU functionality or may inquire with other IOOs that may have procured RSUs with this feature.

- *Seek IOO verification results.* Contact other IOOs to learn what testing results they are willing to share. During the process of verifying successful CI broadcasts, IOOs will likely test if the RSUs are accomplishing the required periodicity of broadcasts, and understand implications of such things as signing messages, broadcasting simultaneous TIMs from the RSU, receiving and checking certificates for incoming BSM messages, etc. The results of these exercises in the verification process may offer insights to the readiness of RSU vendors.

- *Familiarize with OmniAir Certifications.* A list of OmniAir certified products is available at: https://omniair.org/certified-products/, and is expected to include certification of RSUs based on the *CTI 4001 v01 RSU Standard*.

- *Prepare a summary of notes taken during RSU research.* Based on the research conducted based on the bullets above, prepare a summary of notes regarding what was learned about current capabilities of RSU vendors, save this as *Documentation 2.5 Notes on Other RSU Options.*

Basis:

- If RSU has additional capabilities (e.g., RTCM), this may reduce systems deployed at the CI.

Documentation 2.5 Notes on Other RSU Options

RSU Make/Model:____________________

Using the RSU fact sheet/product sheet or specification, note the following information:

1. Is there any statement about meeting the requirements defined in the *CTI 4001 v01 RSU Standard*?
   - ❑ Yes
   - ❑ No

2. Note if any of the following mandatory features are identified for the RSU (these will be needed for your connected intersection)?
   - ❑ PCAP logging
   - ❑ Support for SAE J2735 SPaT, MAP, RTCM messages
   - ❑ Security certificates
   - ❑ Hardware security module
   - ❑ Local Network Interface security

3. Note if any of the following optional features are identified for the RSU (these may be needed based on local preferences or plans for the intersection)?
   - ❑ Support for TIM or BSM messages
   - ❑ Position correction/RTCM message generation
   - ❑ LTE/Cellular connectivity

2.2.2.6 Step 2 – Guidance #2.6: Understand the Security Credential Management System

Overview:

The SCMS provides anonymous trust by issuing digital certificates to approved devices. Devices use these certificates to sign messages they broadcast, and devices that receive messages from CIs will verify the signatures to ensure messages are from a trusted source. Messages are signed using certificates generated and provided from a known and trusted Certificate Authority (CA) (i.e., certificate issuer).

Each message broadcast by the RSU will require a signed security certificate. The RSU may receive messages to broadcast that are either signed by the source or not signed by the source. For messages not signed by the source, the RSU will need to have appropriate certificates and sign the messages before sending.

The IOO responsible for the CI will need to procure the services of an SCMS/Security Backend Vendor to provide security certificates to be attached to the messages as they are broadcast. The *CTI 4501 v01.01 CI Implementation Guide* includes Certificate Issuing Requirements and requirements for the interface between SCMS and RSU and the MAP Server.

The SCMS provider will provide the security criteria that devices must meet to operate within their system. Once authorized, devices are considered trusted actors in the system. A certification process, yet to be developed, will ensure that devices meet performance requirements identified across multiple connected vehicle standards and perform as intended.

SCMS enrollment is required to conduct field validation activities. Initially, certificates issued for the CI will not be recognized and trusted by production vehicles operating RLVW applications. Only after verification takes place will the certificate received contain a field that indicates whether this intersection is verified or not, allowing in-vehicle applications to then trust or not trust the data received based on this "flag".

Certificates are only valid for a limited time period, and devices top-off (request new certificates) as needed. This requires the RSU to enroll in the security provider SCMS exchange.

Guidance:

- IOOs considering or in the process of deploying CIs should develop an understanding of the role and function of security certificates. Background information about the SCMS is available in several resources, as follows:
    - A brief summary of the SCMS is available in a fact sheet developed by the CV PFS, which is available at: https://engineering.virginia.edu/sites/default/files/common/Centers/CTS/CVPFS/resources/CI-Fact-Sheets/CV%20PFS%20SCMS%20Fact%20Sheet%2003072022.pdf .

- United States Department of Transportation (USDOT) Connected Vehicle Deployment Technical Assistance: SCMS Technical Primer (https://rosap.ntl.bts.gov/view/dot/43635);
- USDOT SCMS Fact Sheet (https://www.its.dot.gov/factsheets/pdf/CV_SCMS.pdf).
- The *CTI 4501 v01.01 CI Implementation Guide* includes SCMS requirements (http://www.ite.org/pub/76270782-B7E4-7F75-BC72-D5E318B14C9A);
- The ITE Connected Intersections website (https://www.ite.org/technical-resources/standards/connected-intersections/) contains a list of identified SCMS providers.

- IOOs should familiarize themselves with estimated costs of SCMS. Utah DOT roughly estimates that certificates used in their deployments cost $50 to $75 per year per RSU, with OBU certificates less than that. Another resource that includes information about the costs of CI security is the National Cooperative Highway Research Program (NCHRP) Web-Only Document 289: Business Models to Facilitate Deployment of Connected Vehicle Infrastructure to Support Automated Vehicle Operations (https://nap.nationalacademies.org/download/25946):

- Members of the CV PFS are working in partnership with the OEMs to develop both the process to verify intersections and the process for agencies to obtain OEM recognized certificates through the SCMS providers they contract with. IOOs considering deploying CIs should coordinate with members of the CV PFS for updates on the process of establishing the SCMS verification process defined in Step 7.

- More details on the final established SCMS verification process will be updated when available.

Basis:

- Basic understanding about the SCMS will be critical to Step 3.6.

2.2.2.7 Step 2 – Guidance #2.7: Assess Capabilities of Staff and Contractors

Overview:

During Steps 3 and 4, the guidance will describe advice for procuring the equipment, systems, and services needed to deploy the CI. Steps 5 and 6 will describe the process to test and validate the performance of the procured components against requirements for successfully communicating with in-vehicle OBUs. The intent of this guidance is to support IOOs as they assess their capabilities of internal staff, supporting staff, and contractors that might be used to perform some or all the support activities in steps 3-6.

As of 2022, turnkey CIs are not easily procured, installed, and tested in the way that other transportation equipment is. Instead, considerable configuration and local situation adaptation is required. It is likely that in coming years, more of a "plug and play" approach will become available where low-cost bid solicitations can be used to purchase off-the-shelf solutions that work. Until then, procurement of equipment, systems, and services is still complex.

Some agencies prefer to serve as the integrator and procure devices, software, and hardware from each individual vendor, while others prefer to hire an overall systems integrator to supply it all. There are benefits to both approaches. Examples of the benefits are summarized in Table 5 below.

Table 5. Benefits of the Integrator Role Being Performed by the Agency and an Integrator

Benefits to Agency Serving the Role of Integrator for CI Deployment	Benefits of Procuring an Integrator
• Procuring devices directly from a manufacturer may reduce any mark-up or overhead costs • Possibly increased flexibility in buying from more vendors (not tied to any preferred vendors of the private integrator). • Knowledge and experience gained by the agency active in the initial CI deployment will result in more efficiency in future intersections.	• Will benefit from the integrator's lessons learned through experiences of previous intersection deployments (assuming integrator hired has extensive experience). • Will likely benefit from the integrator being up to date on the latest technologies and approaches (avoids the agency needing to monitor all aspects of the industry). • Will benefit from the relationships the integrator has with device suppliers and software developers. May expedite delivery of devices or reduction of costs.

Guidance:

- Agency staff should examine on-call support contracts to determine if skills are available and contracts possible to support local integration through existing contract mechanisms.
- Agency staff should understand the capabilities of internal staff in signal operations, ITS, operations, and other groups regarding hardware / software skills and experience that are available to support a CI deployment.
- Agency staff should determine the agency's preference on building knowledge and experience internally versus procurement of services from outside vendors. Things to consider:
  - There may be long term benefits of expending more effort on early CIs in exchange for not having to outsource integration for all intersections later if additional CIs are anticipated.
  - While no 'off-the-shelf' product is plug and play now, it is expected that vendors will emerge with more turnkey systems in the future.
  - Prepare internal notes on preferences for procurement and save as *Documentation 2.7 Notes on Options for Procurement* to support decisions in Step 3.

Basis:

- A key decision of Step 3 will be what activities are done in-house and what are contracted. Understanding agency capabilities is critical to this.

2.2.2.8 Step 2 – Guidance #2.8: Understand Capabilities Needed to Support Remote Management

Overview:

A major part of normal CI operations is making sure that channels of communication and implemented business processes remain in place so that disruptions or changes at the intersection that cause broadcast information to be incorrect are detected and addressed as soon as possible, as will be described in greater detail in Step 8. To achieve this, agencies should plan to deploy CI equipment in a way that allows for remote management capabilities.

In this context, remote management is defined as the ability to monitor device performance. As detailed in Step 8, there will be times when it is necessary to disable the RSU temporarily or reset the device due to disruptions that are occurring at the CI, therefore remote management is critical.

As discussed in Step 1 – Guidance 1.5, the agency ATMS may be capable of handling remote management capabilities. If this capability is not available, another mechanism will need to be implemented for operators to remotely verify that the RSU is functioning as intended and to either modify or cease broadcasts when they are not accurate (e.g., due to planned maintenance activities that temporarily close a lane). Remote management therefore generally includes the ability to remotely control the RSU power source to power down and restart the device, communicating new or temporary messages for broadcast in the event of a disruption at the CI, or when performing over the air firmware/software updates.

Guidance:

- Identify the approach to be used to remotely turn off power to the RSU and to restart power to the RSU. The remote restart capability could be as simple as turning off the power to the RSU (e.g., power over ethernet, dedicated power source, or recycling the power to the RSU). This could help the RSU recover from a disruption, or also be used when a disruption (e.g., maintenance activities) is scheduled to occur that would render the broadcast information temporarily inaccurate.

- Identify the approach to load new MAP messages to the MAP Server. MAP messages will not change frequently, but there are several situations where a newer MAP message will need to be created and uploaded to the MAP Server (as identified earlier, this is most commonly the RSU but may also be other locations). The IOO must determine how these will occur (e.g., physically visiting the device and loading the updated message, remote access to move the MAP file).

- Consider if your agency plans to broadcast supporting information in the SPaT message describing the status of the MAP message. In the event of a planned disruption, another option is to provide the capability for the ECLA to broadcast a different SPaT message indicating the SPaT message or MAP message is not currently valid.

- Identify the approach to perform over the air firmware/software updates, ensuring the appropriate individuals or groups have access and communication connections to perform these.

- Identify if the RSU has an internal failure detection function that could be monitored to understand if the RSU broadcast is not functioning properly and needs to be reset or inspected.

- Apply the determined approach for remotely terminating and restarting power to the RSU, uploading MAP messages, and performing over the air firmware/software updates when defining the overall CI design is Guidance #2.9.

Basis:

- As noted in *CTI 4001 v01 RSU Standard* sections 3.3.2.2.1 and 3.3.3.2, RSUs must perform remote restart functions, as well as the health and status monitoring functions described by NTCIP 1218 v01.

2.2.2.9 Step 2 – Guidance #2.9: Develop High Level Connected Intersection Design

Overview:

After completing previous steps, enough information about the signal controller, the need for an ECLA, to role of SCMS, and approach to remote monitoring will allow a high-level design to be determined. This high-level design will impact procurement specifications in Step 3.

As outlined in Chapter 2 of the *CTI 4501 v01.01 CI Implementation Guide*, the most common architecture for a CI, illustrated in Figure 3, includes TSC Infrastructure, an RSU, and secure communications to supporting systems for:

- Remote configuration, control, and monitoring of the CI (identified as TMS).
- RTCM message source.
- SCMS/security back-end.

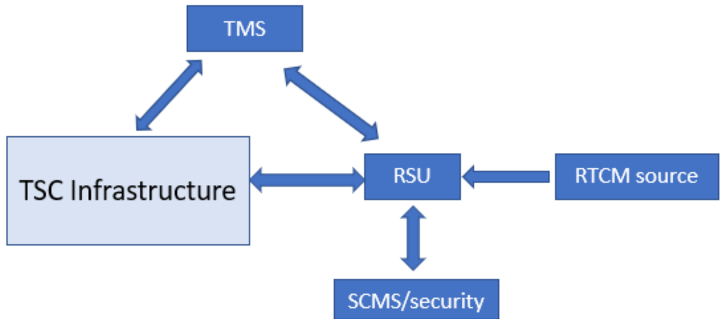


Figure 3. Illustration of a Common Connected Intersection Architecture.

A key decision that needs to be made, based on the findings of Steps 2.1 and 2.2 is the configuration of the TSC Infrastructure. There are two most common options for the TSC Infrastructure, as described below and illustrated in Figure 4 for Option A and Figure 5 for Option B.

Option A - TSC Infrastructure consists only of the signal controller. No other functionality is needed. Possible if:

- No other role for the ECLA (e.g., supporting remote monitoring, processing BSMs, generating TIM messages, generating SSMs) has been identified; and either one of the following is true:
- Signal controller output is: SAE J2735 SPaT messages.
- Signal controller generates: NTCIP 1202v03A (with no protected or permissive turns) and the RSU has functionality to convert NTCIP 1202v03A data into SAE J2735 messages.

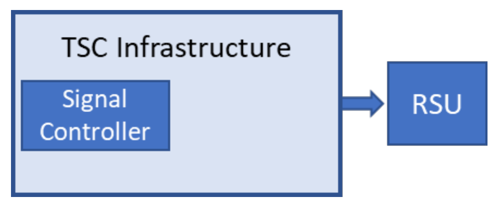


Figure 4. TSC Infrastructure with no ECLA.

Option B - TSC Infrastructure consists of the signal controller and an ECLA. Most likely required if:

- ECLA will generate SAE J2735 SPaT messages because the signal controller outputs TSCBM or NTCIP 1202v03A data and RSU is not capable of converting the data into SAE J2735 messages.
- For CIs supporting signal priority or pre-emption, the ECLA could receive signal request messages (SRMs) and validate requests for priority to generate signal status messages (SSMs) by interfacing with external systems (e.g., transit systems) based on whether the signal has issued priority or not.
- Functionality in the ECLA is needed to support remote monitoring or storing of MAP messages.

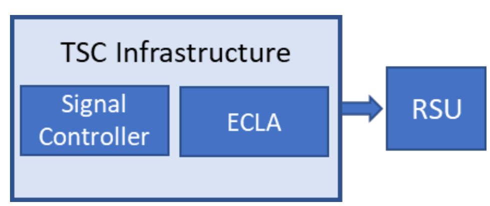


Figure 5. TSC Infrastructure with an ECLA.

<u>Guidance</u>:

- Examine the outcome of Documentation 2.2 List of Needs for an ECLA. If there are needs stated for an ECLA, then the recommended high-level design is to include an ECLA in the TSC Infrastructure.
- Complete Documentation 2.9 while referencing Figure 3 to identify:
  - The candidate RTCM source(s) and the communication mechanism to reach the RSU.
  - The source of the SCMS/security back-end and the communication mechanism for certificates to be provisioned directly to the RSU.
  - The location of the RSU and communications capabilities with the RSU.
  - The location where the MAP message will be stored (e.g., at the RSU, at the ECLA, at the TMS). Suggested approach is:
    - The MAP messages are created using the agency approach and off-line back-ups of all versions of MAP messages are kept in working folders for use or reference in the future.
    - That final validated MAP messages are moved to a MAP server somewhere in the TMS. This could be a location where current MAP messages for all agency operated CIs are stored.
  - That MAP message for each intersection is downloaded from the MAP server to the appropriate RSU or store and repeat broadcast, using the agency preferred approach for downloads. Either:
    - The location of the ECLA (if planned) and a summary of the functions to be performed by the ECLA; or
    - Summary of the Signal Controller output (i.e., J2735 SPaT or NTCIP 1202v03A) that demonstrates an ECLA is not needed.
  - The approach to remotely terminating power to the RSU and restoring power.
- Develop an overall high level design document using the information in Documentation 2.9.

<u>Basis</u>:

- Assembling key decisions reached and an overall plan for the CI will be useful in future steps.

Documentation 2.9 Key High-Level Design Decisions

1. Signal Controller Output will be formatted according to: ______________________________
(Options: TSCBM, SAE J2735, NTCIP 1202v03A, other)
2. There (will / will not) be an ECLA.
3. If an ECLA is planned, the role(s) will be: ____
____
(Options include: address requirements not met by signal controller like real-time message conversion or provision of supplemental data, storing MAP messages, testing / troubleshooting, receive and process BSMs process signal priority requests to adjust signal timing as part of network signal management system, other functions beyond message broadcast)
4. The RTCM source will be: ____
(Options include: state or local CORS network/system, commercially-available CORS data with subscription, deploying RTK base stations near the CI)
5. The communication mechanism for the RTCM information to reach the RSU will be:
____
6. The SCMS/security back-end location will be: ______________________________________
7. The communication mechanism for the certificates to move from the SCMS / security back-end to the RSU will be:
____
8. The RSU location will be: ____
9. The communication capabilities between the RSU and ECLA (if applicable) will be:
____
10. The MAP message will be stored at: ____
(Options: the RSU, the ECLA, or the TMS)
11. The communications approach to upload new MAP messages to the storage location will be:
____
(Options include: physical visit to device to load file, remote access to load file)
12. The communication mechanism for the MAP message to reach to RSU will be:
____
13. If applicable, the location of the ECLA will be: _____________________________________
14. The approach to remotely terminating power and restoring power to the RSU will be:
____

2.2.3 Summary and Outcomes of Step 2

Upon completing Step 2, practitioners should have a better understanding of the existing conditions and options regarding agency systems and equipment at the intersection. The information assembled in this step should include documentation that will be used in later steps, as detailed in Table 6.

Table 6. Documentation Developed in Step 2 for Use in Later Steps

Documentation	Developed as Part of...	For Use in...
Completed Signal Controller NRTM	Guidance #2.1	Guidance #3.1 (and Guidance #2.2)
List of Needs for ECLA	Guidance #2.2	Guidance #3.2
Desired RSU Certifications and Additional Requirements	Guidance #2.3	Guidance #3.3
Downloaded RSU NRTM	Guidance #2.3	Guidance #3.3 (and Guidance #2.4)
Completed Owned RSU NRTM	Guidance #2.4	Guidance #3.3
Notes on Other RSU Options	Guidance #2.5	Guidance #3.3
Notes on Options for Procurement	Guidance #2.7	Guidance #3.3
Key High-Level Design Decisions	Guidance #2.9	Guidance #3.1, Guidance #3.2, Guidance #3.3, Guidance #3.5, and Guidance #3.6

2.3 STEP 3 – DETERMINE PROCUREMENT SPECIFICATIONS

Step 3:
Determine Procurement Specifications

Specifications based on requirements for the CI must be developed to procure the equipment and services needed to deploy a CI. The equipment specifications for various CI system components will necessarily depend on the infrastructure and capabilities that are currently available at the intersection. Likewise, support contractors may be needed to assist the IOO with CI deployment, depending on IOO staff skills.

2.3.1 Objective

The objective of Step 3 is to use the information gathered in Step 1 and Step 2 to develop the specifications necessary for procuring upgrades to existing equipment and/or new equipment and related services in Step 4.

2.3.2 Step 3 Guidance

CI deployers are encouraged to determine the procurement specifications as identified in Table 7 below during Step 3 to support procurement in Step 4 of the CI deployment process. CI deployers should adapt this guidance to adopt to local constraints, conditions, and the specific goals for the CI deployment.

Table 7. Step 3 – Determine Procurement Specifications: Guidance List

Step 3 – Determine Procurement Specifications	Guidance #3.1	Determine Signal Controller Procurement Specifications
	Guidance #3.2	Determine External Control Local Application Procurement Specification
	Guidance #3.3	Determine Roadside Unit Procurement Specification
	Guidance #3.4	Determine MAP Message Procurement or Development
	Guidance #3.5	Determine Radio Technical Commission for Maritime Services Procurement Specification
	Guidance #3.6	Determine Security Credential Management System Procurement Specification
	Guidance #3.7	Determine Test Equipment Procurement Specification
	Guidance #3.8	Determine Field Installation Plans and Specifications

2.3.2.1 Step 3 – Guidance #3.1: Determine Signal Controller Procurement Specifications

Overview:

In order to meet the CI requirements and deploy a CI that can be verified to support OEM production vehicle RLVW applications, some combination of the following four activities are likely to be needed:

1. You will procure or receive upgraded functionality to the existing signal controller. Upgraded functionality to the signal controller would most likely be just a software upgrade and in some cases may be free to your agency, based on your agreement with your controller manufacturer. Regardless of whether costs are incurred, this would most likely not be a bid process but rather a modification to already procured systems and services.

2. You will procure or develop an ECLA to perform functions the signal controller cannot.

3. You will procure a new signal controller for this intersection. If a new signal controller is procured, the CTI 4501 NRTM connected vehicle requirements are only one aspect of what would need to be specified. Other aspects would include topics such as how the controller supports coordination, time of day programs, preemption/priority, logic processes, etc. These may be bigger considerations for your agency when procuring and selecting a controller.

4. You will not need to make any changes to the signal controller.

<u>Guidance</u>:

- During Step 2.1, you were encouraged to work with your signal controller manufacturer or distributor to understand the extent to which the signal controller meets (or can be modified to meet) the CI requirements.

- Work with existing agency procurement or contracting mechanisms to solicit any needed formal proposals or responses from your signal controller manufacturer and/or distributor and determine if upgrading the signal controller is a viable option.

- Use the supporting flow chart shown in Figure 6 and documentation prepared in earlier steps to guide the specification preparation.

<u>Basis</u>:

- Earlier documentation (*Documentation 2.1 Completed Signal Controller NRTM – completed in Step 2.1)* was created specifically for this step.

- Flow chart (see Figure 6 below) will ensure all aspects are considered.

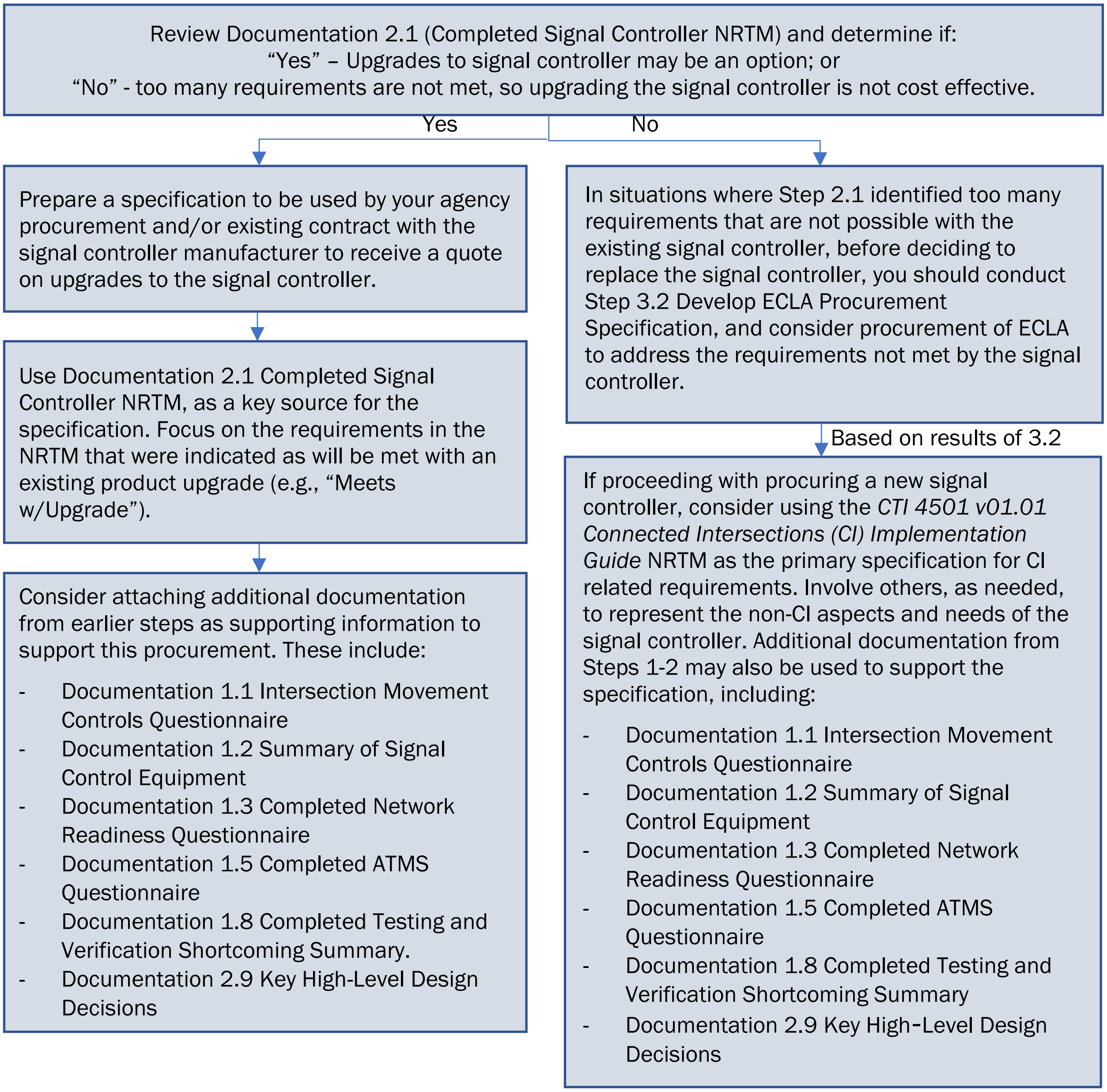


Figure 6. Flow Chart to Support Development of Procurement Specifications for Signal Controllers.

2.3.2.2 Step 3 – Guidance #3.2: Determine External Control Local Application Procurement Specification

Overview:

Early examples where IOOs have deployed CIs that meet the CI requirements have generally included some form of an ECLA (either incorporated into the controller or residing on a separate server). Guidance 3.2 will help you develop procurement specifications to procure an ECLA as a product or through support services to create an ECLA.

Guidance:

- Use *Documentation 2.2 List of Needs for ECLA* as the primary source for the specifications describing the overall function of the ECLA.
- Use *Documentation 2.1 Completed Signal Controller NRTM* as supporting information in the specification, as this documents the requirements as prescribed by the *CTI 4501 v01.01 CI Implementation Guide* and includes the responses from the signal control manufacturer. Emphasize the requirements marked as “ECLA” or “Meets w/Upgrade” and “Not possible”.
- In the specification, emphasize that the ECLA would need to perform all the shortcomings of the signal controller, either represented by Documentation 2.1 or by the signal controller manufacturer’s response to the procurement that results from Step 3.1.
- In the specification, emphasize the additional functionality required as described in *Documentation 2.2 List of Needs for ECLA.*
- Use the following additional documentations prepared in Steps 1 and 2 to provide background into the specifications:
  - Documentation 1.3 Completed Network Readiness Checklist;
  - Documentation 1.4 Completed MAP Server Questionnaire;
  - Documentation 1.5 Completed ATMS Questionnaire;
  - Documentation 1.7 Completed Physical Infrastructure Makeup Questionnaire; and
  - Documentation 1.8 Completed Testing & Verification Capabilities Checklist.
  - Documentation 2.9 Key High Level Design Decisions

Basis:

- Earlier documentation was created specifically for this step.

2.3.2.3 Step 3 – Guidance #3.3: Determine Roadside Unit Procurement Specification

Overview:

If the outcome of Step 2.4 indicated that an agency owned RSU can support this CI, then you can skip Step 3.3 and use the RSU your agency already owns.

In situations where no RSU is available or Step 2.4 has concluded that already owned RSUs will not meet the requirements of this CI, then proceed with Step 3.3 and develop procurement specifications to support the purchase of an RSU.

Guidance:

Prepare a specification for the procurement of the RSU, using the following as input to the specification:

- *CTI 4001 v01 RSU Standard.* Use Documentation *2.3b Downloaded RSU NRTM* as the minimum set of requirements in the specification.
- *Desired Certifications and/or additional requirements.* Use *Documentation 2.3a Desired RSU Certifications and Additional Requirements* to add specifications based on OmniAir certifications and any additional requirements identified in Step 2.3.
- *Other RSU Options.* Use *Documentation 2.5: Notes on Other RSU Options* to identify additional functions you wish to include in the specification above the requirements defined in the *CTI 4001 v01 RSU Standard*.

> *Example:* The Ohio DOT uses the following language for procuring RSUs:
>
> - RSU's shall be OmniAir Certified for DSRC and shall submit certification documentation clearly showing that certification.
> - Vendors shall also be OmniAir certified for C-V2X or show that they are actively working toward certification work to become OmniAir certified for C-V2X (LTE-V2X).

- *Testing and Verification Needs*. The testing and verification performed in Steps 6-7 may have additional requirements beyond those in the *CTI 4501 v01.01 CI Implementation Guide* (e.g., stricter broadcast periodicity requirements)
- *Agency specific specifications* for device resilience to atmospheric conditions (e.g., weather, chemicals, etc.), mounting, or security.
- *Supplement Signal Controller or MAP information.* Refer to Documentation 2.9 Key High Level Design Decisions for any additional functions identified by the RSU that are not planned to be fully supported by the signal controller or the ECLA and may require that data elements be populated by the RSU.

Basis:

- Considerable industry efforts developed the RSU resources to support procurement. Documentation prepared in earlier steps was specifically to support this activity.

2.3.2.4 Step 3 – Guidance #3.4: Determine MAP Message Procurement or Development

Overview:

The SAE J2735 MAP Message is a critical message that must accompany broadcasts of SAE J2735 SPaT Messages. The CV PFS has created a MAP Guidance Document that outlines the steps to perform to create MAP messages that are consistent and support the requirements of the *CTI 4501 v01.01 CI Implementation Guide*.

Guidance:

- Based on the high-level design of this CI, determine the server that will store the MAP messages. This could be the ECLA discussed above, or another existing server, or the purchase and configuration of a new server to be a MAP server to store MAP messages for all CIs operated by the agency. The copy of the MAP message in the RSU will be the operational copy, but agencies should maintain a copy of the current MAP message in the TMS so it could be loaded to the RSU in situations where the RSU loses the copy (e.g., during a restart or replacement of the RSU).

- Download and use the CV PFS MAP Guidance Document to establish and execute a process to create the initial MAP message for this intersection and to update the MAP message as needed. If internal staff will be responsible for preparing the initial MAP message and updates to the MAP message, no procurement documents are needed.

- If an outside contractor or vendor will be used to create MAP messages, the MAP Guidance Document should serve as the primary resource for describing the tasks to be created by the contracted vendor, with the following notes:

  - Some aspects of the steps described in the MAP Guidance Document may be conducted by the agency (e.g., field surveys, provision of signal timing plans). Therefore, the agency should review the MAP Guidance Document and identify those activities to be performed by the agency and those to be included in the contract written based on the procurement.

Basis:

- Intent of the MAP Guidance Document.

2.3.2.5 Step 3 – Guidance #3.5: Determine Radio Technical Commission for Maritime Services Procurement Specification

Overview:

In Step 1.6, you downloaded the *CTI 4501 v01.01 CI Implementation Guide* NRTM and highlighted the requirements specific to RTCM. During Step 1.6, you also completed a questionnaire about your agency options for the source of RTCM messages (Documentation 1.6b Completed CORS/RTCM Questionnaire).

Additionally, during Step 2.5 when exploring capabilities of other RSU manufacturers, you may have discovered that there are RSUs that now serve as the source for RTCM data and messages.

Finally, additional documentation created in Step 1 has helped to assemble information about the network and supporting systems that may support the procurement of RTCM data.

Additional information about RTCM is summarized in a fact sheet developed by the CV PFS, which is available at: https://engineering.virginia.edu/sites/default/files/common/Centers/CTS/CVPFS/resources/CI-Fact-Sheets/CV%20PFS%20RTCM%20Message%20Fact%20Sheet%2012012021.pdf

Guidance:

- Use the flow diagram in Figure 7 as a suggested approach to developing RTCM specifications and assessing options for RTCM.

Basis:

- Flowchart reflects a repeatable procedure to assess RTCM options and leverage documentation prepared in Step 1.

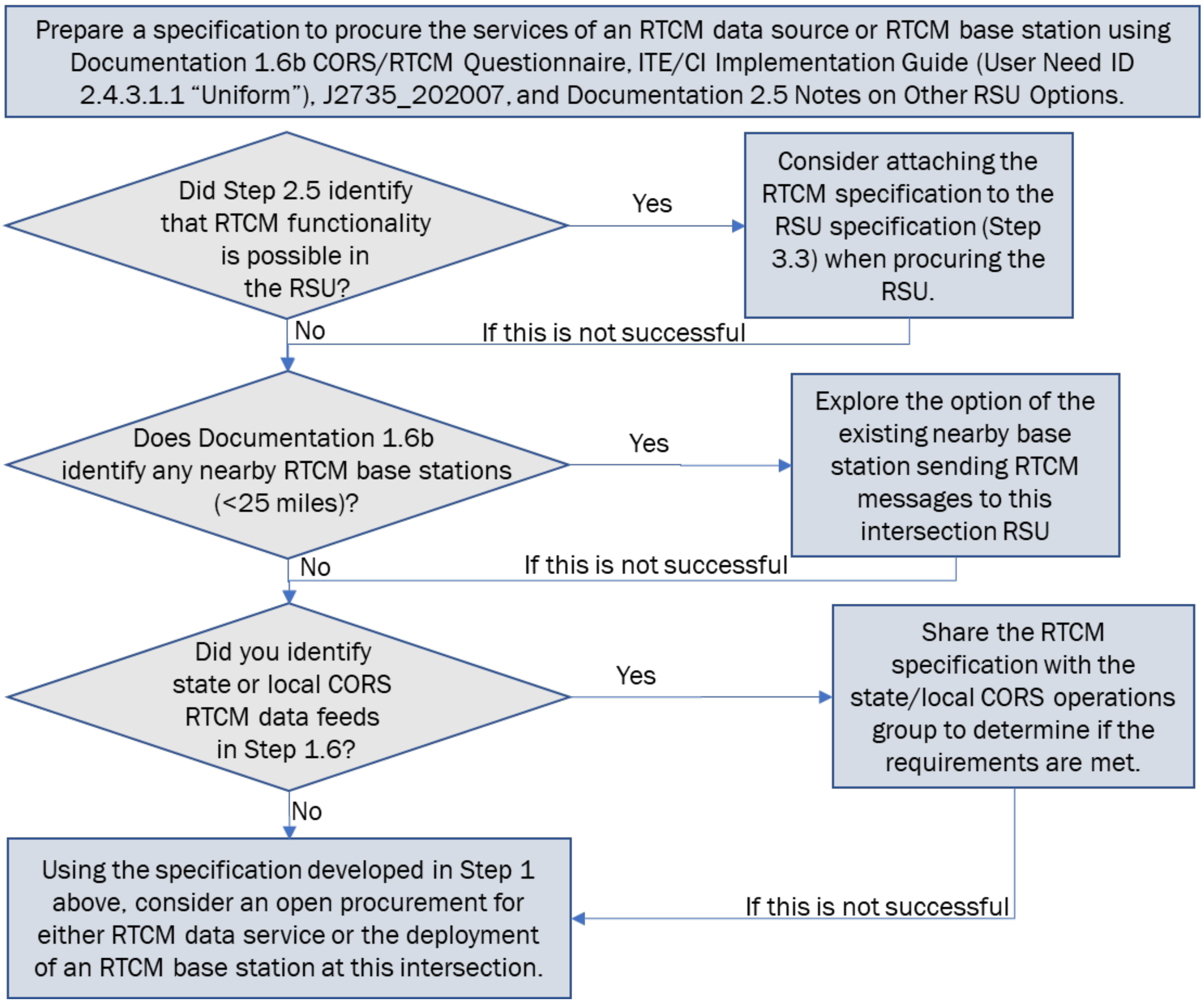


Figure 7. Flow Diagram with a Suggested Approach for Developing RTCM Specifications

2.3.2.6 Step 3 – Guidance #3.6: Determine Security Credential Management System Procurement Specification

Overview:

As noted in Step 2.6, the SCMS provides anonymous trust by issuing digital certificates to approved devices. To successfully implement SCMS, the IOO responsible for the CI will need to procure the services of an SCMS/Security Backend Vendor to provide security certificates to be attached to the messages as they are broadcast. The *CTI 4501 v01.01 CI Implementation Guide* includes Certificate Issuing Requirements and requirements for the interface between SCMS and RSU and the MAP Server.

However, using SCMS services that meet these functional requirements does not ensure that the in-vehicle OBUs will acknowledge or trust the certificates. It will be up to the receiving entity to determine which certificates they trust. For this reason, IOOs need to understand how to acquire SCMS certificates that are trusted by the OEMs that will be operating in-vehicle RLVW applications – a process that is still pending as of the publication of this Guidance.

Guidance:

- *Ensure that you are on the path towards strict adherence to the requirements defined in the CTI 4501 v01.01 CI Implementation Guide and the CTI 4001 v01 RSU Standard.* This document repeatedly references and refers readers to these two documents, and compliance with these requirements (including any future amendments or updates) cannot be emphasized enough.

- *Inquire about the status of certificates trusted by the OEMs.* A process (currently under development) to verify that intersections are broadcasting messages that are accurate, consistent, and reliable will facilitate the release of security certificates to IOOs containing a "flag" indicating the intersection is verified. These certificates will be required by the OEMs for the message to be trusted by them.

- *Seek input from other IOOs.* Reach out to IOOs that have successfully completed procurement of SCMS services or that are in the process of procuring services. Lessons learned and examples of specification language describing requirements are very transferable from one IOO to another.

- *Prepare the specifications to Procure the services of an SCMS provider.* Develop a procurement specification based on the requirements in CTI 4501 v01.01 CI Implementation Guide and the CTI 4001 v01 RSU Standard. In addition to these requirements, additional aspects to consider include:

    - *Document local restrictions and preferences.* In preparation for procuring an SCMS provider, IOOs should work with their agency IT personnel to understand agency security and firewall restrictions and identify a mechanism for the RSU to remotely receive new certificates from the SCMS provider.

    - *Estimate current and projected security needs.* Consider both the current and future plans for CI deployments to include references to scalability in the procurement of SCMS services. For example, estimate the number of new CIs to be deployed each year of the contract with the SCMS provider.

    - *Identify all messages requiring certificates.* IOOs should Identify all the messages that will be broadcast by the CI and require certificates. Individual security certificates are tailored to certain messages. If the agency understands all the messages to be supported by the CI, the services to provide these certificates can be procured together. However, situations may also occur where certificates need to be added later. For example, a CI may start by broadcasting SPaT and MAP messages, but later may add Signal Status Messages (SSM). Adding a new message broadcast would require updating the certificates to support this.

- *Ensure that the specifications require the selected SCMS provider to be authorized to issue SCMS certificates with the "flag" indicating that the intersection has been fully verified*. A key requirement of the SCMS provider is that they have the ability and authority to verify the IOO CIs and issue certificates with the indication that the intersection has been fully verified. (Note that this capability has not yet been developed by the certificate providers.)

- *Clarify the role of reprovisioning and updating the certificates*. Certificates issued by the SCMS provider go stale after a certain period of time, and a requirement for the SCMS provider will be to conduct ongoing provisioning of new certificates. Ensure this process is defined in detail in the SCMS procurement specification.

> *Example*: The Ohio Department of Transportation (DOT) has published guidance relating to PSIDs and SCMS in order to ensure alignment of PSID profiles that will be recognized by OEMs. ODOT also has a security enrollment checklist to avoid hacking issues. These documents are available for reference at:
> - https://drive.ohio.gov/programs/av-cv/cv-av-systems/security/03-enrollment-process
> - https://drive.ohio.gov/programs/av-cv/cv-av-systems/security/02-security-checklist

Basis:

- CTI 4501 v01.01 CI Implementation Guide security requirements.
- Feedback from SCMS Manager and participating OEMs regarding the need (being developed) for CI verification before a "flag" is attached to the certificates indicating this.

2.3.2.7 Step 3 – Guidance #3.7: Determine Test Equipment Procurement Specification

Overview:

Testing and verification of the CI will be needed before obtaining security credentials that are used by OEM production vehicles. These testing and verification processes are rigorous and require access to data from the signal controller to conduct the detailed analysis to determine if the SPaT data is accurate and complete.

In order to test and verify the accuracy and completeness of the SPaT data at this intersection, the group(s) performing the testing will need adequate access to sufficient data, which will require various testing tools, software, and other equipment, as detailed in the Documentation 3.7 Checklist and shown in Figure 8.

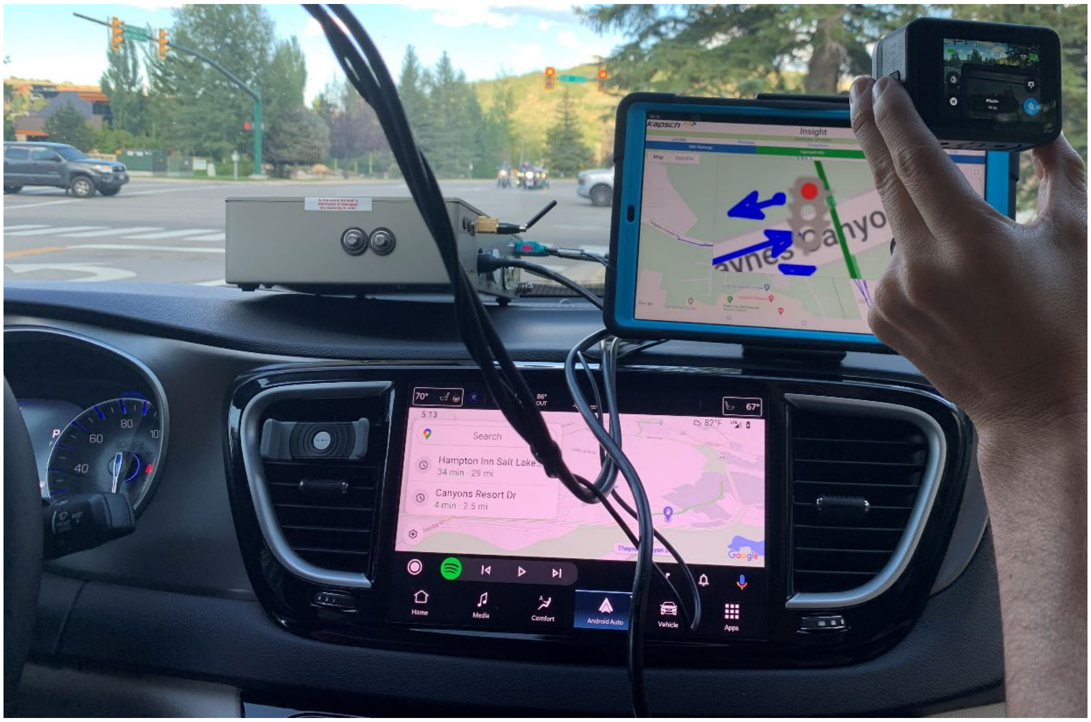


Figure 8. **Testing Tools, a High-Resolution Camera, On-Board Unit, and User Interface are Some of the Test Equipment Needed to Conduct Testing and Verification Activities**

<u>Guidance</u>:

- Use Documentation 1.8 Completed Testing & Verification Capabilities Checklist and complete Documentation 3.7 Checklist of Facilities and Equipment Needed for Testing to assemble specifications for test facilities, equipment, and software that is needed.
  - Explore options for borrowing test equipment that might be available for loan from USDOT or neighboring agencies.
  - Include any of the required tools that the agency does not possess (or cannot acquire temporarily) in a procurement as part of Step 4.
- Supplement with additional test equipment, including:
  - *At least one vehicle with one OBU*. The OBU should be able to generate its own PCAP files that can be extracted from the device OR can interface with an external device with a network packet sniffer tool.
  - *Laptop with Wireshark Packet Analyzer software to decode/log SPaT/MAP/RTCM*. Wireshark is a network packet sniffer and protocol analysis tool. This tool allows the live capture and storage of network PCAP data from the OBU. The tool should ideally have a

(ASN.1) decoder so SAE J2735 message payloads can be decoded and analyzed directly in the tool. The tool should also ideally be able to export dissected packet data into intermediate file formats (e.g., csv, json) so that the data can be further analyzed using other external tools (e.g., Excel) or custom software can be built to analyze the data. Verification of Wireless Access in Vehicular Environments (WAVE) Service Advertisement (WSA) / WAVE Routing Advertisement (WRA) and RTCM message content, as well as capture of CV messages in PCAP and JavaScript Object Notation (JSON) is done using PCAP data from the OBU.

- *High-framerate camera and associated player software*. The camera (e.g., GoPro Hero 9) and software combination should allow for video replay and advancement in a frame-by-frame fashion. For example, a framerate of 240 frames-per-second can be replayed in super slow-motion mode to capture intervals of less than 5 milliseconds. Additional video processing software (e.g., ffmpeg) may be desired to insert a relative timestamp (i.e., seconds since the beginning of the video) as a text overlay near the bottom of the video, as shown in Figure 9.

Figure 9. Video Processing Software can Add a Relative Timestamp to Video to Facilitate Analysis, as shown in the Red Box.

- *Kapsch CV Test Tool (CVV) laptop software and CVV OBU*. This equipment allows users to visualize SPaT and MAP messages in real time by interfacing with the OBU described above and display on a user interface.

- *Crash Avoidance Metrics Partnership (CAMP) Software tools*. These mapping tools assist with post-visualization of the MAP/SPaT message and related data. One tool accepts a .csv file containing a record for each message, with the following columns: epoch timestamp, message id, json-encoded version of the message payload, signature indicator, which some OBUs (e.g., Kapsch) automatically produce. Note that the CAMP tools currently require permission to access, and ESRI ArcGIS Software could be used as an alternative. Additional details about use of this Utility are available in the CTI 4502 v01 CI Validation Report.

- *Survey equipment.* As an example, a Trimble R12 global navigation satellite system (GNSS) receiver and Trimble TSC3 data controller was used to conduct a survey of CIs in Marysville, Ohio.

- *Bench test tools* (hand tools like pliers, screw drivers, socket set, etc.; 110 volts of alternating current (VAC)-to-12 volts of direct current (VDC) power supplies; Category 5 (CAT5) Ethernet patch cables to connect laptops with devices being tested).

Basis:

- Combination of information gathered in earlier steps combined with resources developed during the CV PFS CI Project represent a thorough understanding of equipment needed for testing.

Documentation 3.7 Checklist of Facilities and Equipment Needed for Testing

Typical facilities for conducting off-line (bench) testing (see CI Test Plan Section 6.6.1):

- ❑ Workbench space
- ❑ Surge Protection power strips
- ❑ A Conference Room, with whiteboard and/or flipcharts, etc.
- ❑ Internet access

Typical equipment for conducting off-line testing (see CI Test Plan Section 6.6.1):

- ❑ Agency Test Plan and Documentation Records
- ❑ Two (2) RSUs of each manufacturer to be tested
- ❑ Three (3) laptops
- ❑ Software test tools: Kapsch CVV Test Tool, CAMP Tools, etc.
- ❑ Bench test hand tools: pliers, screw drivers, socket set, etc.
- ❑ 110 VAC-to-12 VDC Power supplies
- ❑ Assortment of CAT5 Ethernet patch cables (for connecting laptops to devices being tested)
- ❑ Wireshark Protocol Analyzer capable of decoding and logging SPaT, MAP and RTCM
- ❑ Survey equipment (e.g., Trimble R12 GNSS receiver and Trimble TSC3 data controller)
- ❑ Other relevant software tools used during device certification testing.

Typical equipment for conducting field validation testing (see CI Test Plan Section 6.6.1):

- ❑ At least one vehicle with one OBU
- ❑ High framerate camera and associated software
- ❑ Laptop
- ❑ Assortment of CAT5 Ethernet patch cables (for connecting laptops to OBU device)
- ❑ Wireshark Protocol Analyzer capable of decoding and logging SPaT, MAP and RTCM
- ❑ Survey equipment (e.g., Trimble R12 GNSS receiver and Trimble TSC3 data controller)
- ❑ Other relevant software tools used during device certification testing.

2.3.2.8 Step 3 – Guidance #3.8: Determine Field Installation Plans and Specifications

Overview:

Another aspect of Step 3 is to develop plans, specifications and estimates to procure field construction contractors to mount RSUs, pull cables, install cabinet updates, and other field activities needed to deploy the CI.

It is recognized that agency staff may perform installations and this step may not require specifications or plans to be used in procurement.

Guidance:

- Determine the overall approach to installation of CI field equipment to be performed in Step 5 (e.g., in-house installation or contractor installation).
- Develop agency-required construction plans (i.e., as-builts or design documentation) as per local approaches to construction that could be used as specifications for the procurement of construction services in Step 4 to support installation in Step 6. Construction plans for CI systems will typically include:
    - Locations where RSUs will be mounted, including mounting devices and mounting heights.
        - mounting instructions from vendor products should be reviewed and considered during this development);
        - Maximum mounting heights are regulated by the FCC. From a procurement standpoint, a mounting range will indicate to a potential contractor of a bucket truck is needed to mount the RSU.
    - Descriptions of cable connections needed to connect the TSC, TMS, SCMS source, and RTCM source to the RSU; and
    - Additional power supplies (if needed) or communications capabilities added.

Basis:

- Required to support Step 6 installation.

2.3.3 Summary and Outcomes of Step 3

Upon completing Step 3, practitioners should have a completed set of specifications needed to procure new equipment, upgrades to existing equipment, and/or services to deploy CIs as part of Step 4. Example CI procurement specifications that have been used by IOOs are available for reference in Table 8.

Table 8. Sample CI Procurement Specifications

Agency	Description	Link
Ohio DOT	Procurement specification for RSU certification by OmniAir	Presented in Guidance #3.3 above.

2.4 STEP 4 – PROCURE SYSTEM COMPONENTS

Step 4:
Procure System Components

IOOs use a variety of mechanisms to procure equipment and services. The purpose of this step is not to dictate an approach that IOOs should take to procure CI system components, but to provide an understanding of considerations specific to CIs that should be incorporated with existing procurement mechanisms that are used by the IOO.

2.4.1 Objective

The objective of Step 4 is to procure upgrades to existing equipment and/or new equipment and related services that will enable a successful CI deployment. Specifically, this step leverages the procurement specifications developed in Step 3 to follow the agency procurement approach, while also identifying additional considerations that IOOs should factor into their procurement.

2.4.2 Step 4 Guidance

CI deployers are encouraged to follow the guidance for procuring system components and field construction activities as identified in Table 9 below during Step 4. CI deployers should adapt this guidance to adopt to local constraints, conditions, and the specific goals for the CI deployment.

Table 9. Step 4 – Procure System Components: Guidance List

Step 4 – Procure System Components	Guidance #4.1	Consider Scalability to Expand Network of Connected Intersections
	Guidance #4.2	Consider Upward Compatibility to Evolving Specifications
	Guidance #4.3	Consider Scheduling
	Guidance #4.4	Follow Agency Practices to Procure Equipment and Services

2.4.2.1 Step 4 – Guidance #4.1: Consider Scalability to Expand Network of Connected Intersections

Overview:

Agencies should consider their near and mid-term plans for CIs when procuring equipment or services in order to make sure that the procurement process can support future intersections to the extent possible.

Guidance:

- When procuring signal controllers (or upgrades to existing), consider options for additional intersections.

- When procuring RSUs, consider options to extend the procurement for additional intersections, and consider procuring a pool of qualified RSU vendors that will allow purchases of RSUs from a mixture of vendors without re-procurement.

- If procuring an ECLA, consider that the ECLA software will ideally be deployed in other CIs developed by the agency. Therefore, the result of the procurement process should allow for multiple uses of the software and adaptations (as needed) to support other intersections.

- Consider including line items for optional, additional tasks and equipment to deploy additional CIs, pending agency approval, available funding, and/or successful deployment of initial CIs.

- For field installations of CI equipment, if your agency has near-term plans to deploy multiple CIs, consider one procurement to perform installations of support infrastructure at several intersection installations (e.g., RSU mounts) even if all CIs are ready for installation.

Basis:

- Utah DOT success in procuring multiple RSU vendors.

2.4.2.2 Step 4 – Guidance #4.2: Consider Equipment Lifecycle to Accommodate Compatibility with Evolving Specifications

Overview:

As procurement documents are being developed, take steps to ensure that specifications support upward compatibility to new (future) specifications to the extent possible, as well as funds for:

- Routine maintenance to preserve functionality over the device lifecycle.

- Make necessary firmware and hardware updates as updates are available or as new security requirements need to be implemented.

- Monitor any updates to the CTI standards (i.e., the Connected Transportation Interoperability (CTI) 4501 v01.01, and the CTI 4001 v01 Roadside Unit (RSU) Standard) and make updates or changes to the deployments, as needed. Both standards are expecting updates in the near future.

- Replacing equipment sooner than anticipated due to new CI requirements.

For example:

- Upgrades to signal controllers may soon support new features of the NTCIP standard, addressing known limitations that are challenges to CIs.

- The NTCIP standard may be updated.

- Updates to SAE standards may impose different requirements than exist today.
- Other updates or changes may be made to reflect CI Guidance Requirements that are not possible from signal controllers today, which are anticipated to be made in the future (e.g., assured green time).
- Signal controller upgrades may replace the role performed by other components at the CI (e.g., functions currently done by an ECLA, such as the activities done by the ECLA to generate the SPaT message).

Two examples of how the evolving industry may impact procurement are:

1. During the procurement process, industry standards or specifications may change.
2. After successful deployment, industry advances (e.g., a new version signal controller, NTCIP, or updated RSU) may be beneficial to implement without the need to repeat the procurement process.

Guidance:

- When procuring signal controllers, RSUs, and ECLAs, consider the inclusion of language that:
  - Accounts for standards updates, such as: "conform to the most recent version of the SAE J2735 standard."
  - Includes delivery of version upgrades with agreed price parameters.
  - Includes contingency funding to update equipment, as needed (e.g., adjust the RSU when the signal controller is updated).
  - Include a provision to receive firmware and software updates as they become available, to the extent possible, with no additional costs. The key focus should be on receiving controller or RSU upgrades that improve performance or reduce reliance on other systems (e.g., the ECLA).

Basis:

- Input from CV PFS members based on experience.

2.4.2.3 Step 4 – Guidance #4.3: Consider Scheduling

Overview:

Scheduling can play a major role in technology deployments, particularly for newer technologies that are not yet widely deployed. CIs have the same scheduling challenges as other technology deployments as well as some additional challenges, such as FCC licensing and coordination with external verification testing.

Scheduling decisions should include several considerations:

- Consideration for timing the procurement based on other projects (e.g., if the agency is procuring and deploying OBUs on fleet vehicles, or other construction activities near the CI).
- Industry availability of CI components, such as RSUs, RTCM sources. Note that some CI components may have a very long delivery time.
- The potential need for upgrades (or replacements) to the signal controller at the intersection.
- FCC licensing processes and procedures. At the time this Guidance was created, a final C-V2X licensing process has yet to be defined. Once defined, the response time of the FCC will not be known until industry experiences with the new process are documented.
- Vehicle verification processes are yet to be defined but may introduce delay in finalizing CIs.

Guidance:

- When defining a schedule, work with other IOOs in the industry (e.g., through groups like the CV PFS, AASHTO CAT Working Group, ITE, etc.) to understand current time schedules for aspects such as FCC licensing, RSU product availability, and vehicle verification processes.
- Include contingency plans, or at least have options available in case the CI deployment is delayed for any reason and interferes with other activities.
- Consider the realistic deployment timeline when procuring equipment with warranties to avoid situations such as a device being received and the warranty starting months (or years) before field deployment can occur.
- Determine what field installations can be performed before bench testing is completed (e.g., final installation of the RSU should follow bench testing, but the mount and communications may be installed earlier to accommodate timelines.

Basis:

- Input from CV PFS members based on experience.

2.4.2.4 Step 4 – Guidance #4.4: Follow Agency Practices to Procure Equipment and Services

Overview:

The documentation developed and/or referenced in Step 3 should contain the specifications and requirements needed by the agency to procure the equipment, systems, and support to deploy CIs. The nature of the procurement process will vary by agency. Agencies may wish to consult with several other deploying agencies in advance to research various options available, if they have not already done so. Some examples of solicitation processes used or explored by other agencies have included:

- Procurement of components of a CI in phases (e.g., an initial "request for information" or "request for qualifications" followed by a formal "request for proposals").
- Leveraging existing contracting mechanisms (e.g., approved vendors or existing ITS on-call contracts) that may help to build local knowledge of CI components to benefit future local deployments.
- Separating the procurement process into different aspects of the CI (e.g., physical system components in one solicitation and technical support or software development in a separate solicitation, field deployment in a separate solicitation, validation and testing in another procurement).
- Including the CI deployment as part of a larger contract (e.g., a corridor reconstruction project), or be included as part of a funding grant application, which might change the procurement process.

Guidance:

- Practitioners are advised to examine available options for the CI procurement and select the procurement approach that makes the most sense for their local situation and plans for CI deployments.
- Practitioners should use all documentation developed in prior steps to compile one or more bid solicitation(s) that contains all the specifications and requirements needed by the agency to procure the complete CI system, including any additional resources needed for operations and maintenance (see Step 8).
- During the review and consideration of proposals, the review team should verify that each proposed system will meet the specifications before delving further into the details of the proposal and evaluating it. The review team should include staff with adequate expertise who are familiar with CIs and technology deployments.

Basis:

- Documentation prepared in earlier steps is intended to support this step but recognized that local agency procurement options and limitations will need to be adhered to.

2.4.3 Summary and Outcomes of Step 4

Upon completing Step 4, practitioners should be ready to issue a procurement and select contractors and vendors to make upgrades to existing equipment, provide new equipment, and/or provide technical support for testing and deployment.

2.5 STEP 5 – ASSEMBLE AND TEST SYSTEM OFF-LINE (BENCH TESTING)

Step 5:
Assemble and Test System Off-line (Bench Testing)

As actual production vehicles start using the data broadcast from CIs, it is critical that the broadcasts of SPaT, MAP, and RTCM are providing the correct information and using messages that conform to valid standards, so that the vehicle does not give the driver false warnings. Bench testing is a mechanism to test and discover any needed changes before field deployment. Bench testing can test for and help identify user configuration errors, such as the signal groups in the SPaT message not correctly corresponding to the signal groups in the MAP message. Bench testing is not a substitute for field validation.

- Traffic Engineers are familiar with the concept and process of bench testing traffic signal controller and signal head combinations at a traffic signal shop or similar location. Bench testing is done to test system functionality without needing to be in the field or at an intersection (therefore to not disrupt normal signal operations). Bench testing is not only conducted when the signal is initially installed, but often the bench test equipment and setup is maintained to allow additional follow-up tests to be conducted with each firmware change to the signal controller and signal timing changes.
- When adding connectivity to an existing signalized intersection (or deploying a new signal controller that is connected) the role of bench testing is similar. Use of a controlled environment allows for basic testing of the performance of the components of the planned deployment but is not a substitute for field validation testing after installation at the intersection. In addition to testing core performance of the system, bench testing also allows for more efficient testing of selected situations (e.g., the system can be transitioned into all flashing red to test the SPaT message that is generated, etc.).

CI deployers may benefit from understanding the role of bench testing in relation to other CI testing that will be performed, as illustrated in Table 10 below.

Table 10. Role of Three Types of Testing in Deploying a Connected Intersection

Type of Testing and Location	Role
Bench Testing (Off-line at a DOT facility)	- **Before CI deployment Functionality Tests** – Is the CI accomplishing the intended 100 ms time interval of message broadcast (i.e., SPaT message generation, communication to the RSU, and transmission periodicity of the RSU all occur regularly at a frequency of 100ms). Do the SPaT messages accurately describe the signal controller status (specifically, are the start time and duration of Yellow Phase accurately represented?) Are the signal controller data converting to SPaT messages correctly? Are MAP messages formatted correctly?

	- **Before CI deployment Situational Tests** – How does signal controller data convert to SPaT messages during situations (e.g., all red flash, manual override, etc.) - **After CI deployment Troubleshooting** – Bench troubleshooting to isolate which device, hardware, or software are not performing correctly and to test corrections. - **After CI deployment Firmware Updates** – Tests after each firmware upgrade to either the signal controller, RSU, or ECLA.
Field Validation (At the Intersection / Operational System)	- **SPaT, MAP, RTCM Message Format Testing –** Are messages complete and properly formatted? - **SPaT Content and Broadcast Periodicity Testing –** Are SPaT messages accurate and received by an OBU within the allowed latency? - **MAP Content Testing –** Are MAP messages accurate?
Vehicle Verification (At the Intersection / On-board Application)	- **Ability for OBU Applications to receive complete, accurate messages, and specifically for OBU applications using production grade GPS receivers to identify correct lanes of travel based on the MAP message and RTCM corrections received.**

2.5.1 Objective

The goal for Step 5 is to help practitioners to understand:

- The need for validation and what needs to be validated.
- The resources available and what staffing, equipment, and actions they should expect to do.
- How to perform bench testing by using the resources described in this section.

By following the guidance in Step 5, practitioners should understand the role of bench testing, and be able to develop a local approach for testing all CI requirements using a combination of bench testing and field validation that makes the most sense for the local conditions, constraints, and available resources.

2.5.2 Step 5 Guidance

CI deployers are encouraged to assemble and test the procured system off-line as outlined in Table 11 below during Step 5. While this guidance encompasses the testing of requirements specified by the *CTI 4501 v01.01 CI Implementation Guide*, CI deployers have some flexibility in testing each requirement either in the field or as part of bench testing. Deployers should consider local constraints, available resources and equipment, and any additional local applications or requirements that may be desired (e.g., transit signal priority) for testing in either the bench test environment, as part of field validation, or both.

Table 11. Step 5 – Assemble and Test System Off-Line (Bench Testing): Guidance List

Step 5 – Assemble and Test System Off-Line (Bench Testing)	Guidance #5.1	Download and Familiarize with Resources to Support Off-line (Bench) Testing
	Guidance #5.2	Develop Local Approach to Off-line (Bench) Testing
	Guidance #5.3	Assemble and Configure the Off-line (Bench) Test Environment
	Guidance #5.4	Collect Data for Off-line (Bench) Test
	Guidance #5.5	Analyze Off-line (Bench) Test Data

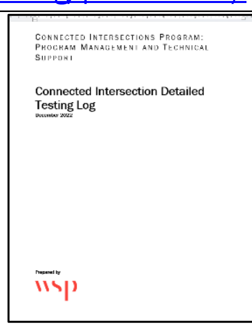
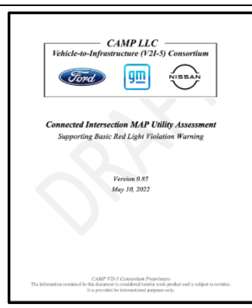
2.5.2.1 Step 5 – Guidance #5.1: Download and Familiarize with Resources to Support Off-line (Bench) Testing

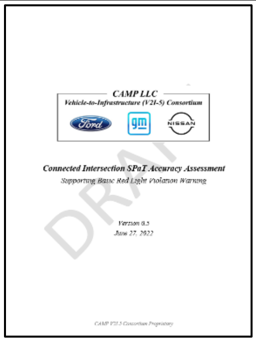
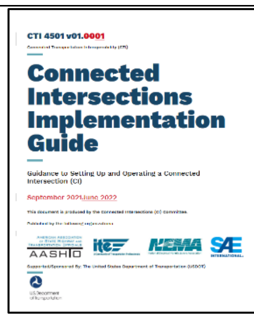
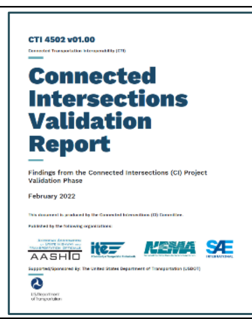
Overview:

Several resources (i.e., documents and on-line utilities) have been created to support the overall validation of CIs. While the primary emphasis of these documents is typically on field validation, these resources are valuable to bench testing and should be downloaded and considered during the bench testing process. These include the seven resources described in Table 12.

Table 12. Resources to Support Off-Line (Bench) Testing.

Resource and Summary	Key Contents	Relationship to Bench Testing
CI Test Plan. Comprehensive test plan to test for basic RLVW functionality. Test activities exclude a limited set of requirements not related to basic RLVW and may not fully test CIs for all OEM applications. This document describes CI test activities completed for Ohio, Georgia, and Utah.  Readers may use this to inform their testing activities or adapt this to their local situation. Source: CV PFS. Available at this link.	- Items to be tested - Test Site Activities - Test Roles - Test Tools - Test Environment	Description of the role of bench testing and test activities to support it. 120 test case tables defining what needs to be tested for all requirements. A portion (or all) of these test cases are likely to be performed in bench testing.
CAMP SPaT/MAP Utility, version 1. On-line tool that allows the upload of JSON files and processes	- On-line utility - Described in related documents prepared by CAMP	Bench testing data collected at the RSU output can be captured as a PCAP file, converted

Resource and Summary	Key Contents	Relationship to Bench Testing
them to analyze SPaT and MAP messages. Analyses include: • SPaT message format: Are all required fields populated and values within allowable bounds? • MAP message format: Are all required fields populated? • SPaT broadcast periodicity. Additional details about use of this Utility are available in the *CTI 4502 v01 CI Validation Report* listed below. Source: CAMP, developed in Ann Arbor project, enhanced during ITE/CI validation. On-line access is not currently available, but a report summarizing this is expected to be posted to the CAMP LLC website at: https://www.campllc.org/publications/.		to JSON, and uploaded to this utility. The utility will provide analysis.
CI Detailed Testing Log. Describes the validation methodology recommended to test each requirement, together with designated space to enter results and explanation as testing is conducted.  Connected Intersections Program: Program Management and Technical Support Connected Intersection Detailed Testing Log Source: CV PFS. Available at [this link]().	120 tables identifying all requirements to be tested, method of testing each, and results and explanation	A template that agencies can customize and complete their "results and explanation" as they test. A completed version prepared during CV PFS testing in Utah is available as part of the Utah DOT Test Results Report.
CI MAP Utility Assessment Supporting Red Light Violation Warning. Describes an available on-line utility that can be used to test MAP message format and MAP accuracy if accompanied by drive data collected by an OBU.  CAMP LLC Vehicle-to-Infrastructure (V2I-S) Consortium Connected Intersection MAP Utility Assessment Supporting Basic Red Light Violation Warning	- Description of the online MAP utility - Description of how to use the MAP utility to test MAP format and MAP accuracy	- Document describes the use of the CAMP utilities - CAMP utilities defined in another resource below - MAP message format can be tested during bench testing (or prior)

Resource and Summary	Key Contents	Relationship to Bench Testing
Source: CAMP LLC. Version 0.90 August 16, 2022 available at: [this link]().		
Connected Intersection SPaT Accuracy Assessment: Supporting Basic Red Light Violation Warning. Describes the data collection and analysis for two key items critical to success of Basic RLVW applications: Yellow phase duration accuracy and SPaT transmission periodicity.  Source: CAMP LLC. Version 0.9 September 28, 2022 available at [this link]().	Describes a process for testing SPaT accuracy and relates to the utility developed by CAMP that is planned to allow automated assessment of Yellow phase duration and SPaT transmission periodicity.	If the signal controller / ECLA / RSU combination is not able to produce accurate yellow interval time durations in bench testing, they should be corrected before advancing to field deployment. This (eventual) automated process will support testing.
CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide. Provides details about signal controller requirements to satisfy basic data needs for RLVW applications.  Source: ITE. Available at [this link]().	The NRTM identifies the requirements that are mandatory, conditional, or optional.	Provides additional details of each requirement that may be useful when preparing for and conducting testing.
CTI 4502 v01 Connected Intersections Validation Report. Summarizes findings from the 2021 ITE CI Program validation phase.  Source: ITE. Available at [this link]().	Describes data collection and analysis for testing, including information about the CAMP tools used to verify MAP and SPaT messages.	Provides additional details about the CAMP SPaT/MAP Utility, which may be used during bench testing.

<u>Guidance</u>:

- In early guidance sections, you should already have downloaded the *CTI 4501 v01.01 CI Implementation Guide*, developed by ITE. Review this document, as needed, for specific questions about the CI requirements.

- Download and become familiar with the CV PFS CI Test Plan document:
  - Carefully review Chapter 6 to understand test site activities related to bench testing to understand:
    - Testing Approaches;
    - Test Roles;
    - Schedule; and
    - Test Tools.
  - Review the Test Cases described in Chapter 8. Note that the test cases in Chapter 8 are also included in the CI Requirement Validation document.
- Download and familiarize with the CI Requirements Validation documents (note: completed documents from Ohio, Georgia, and Utah are resources to support completing the template version).
- Download and familiarize yourself with the CAMP developed CI SPaT Accuracy Assessment document.
- Locate and become familiar with the CAMP-developed Utility for SPaT/MAP Message Assessment. Additional details about the use of this tool are available in the *CTI 4502 v01 CI Validation Report*.

Basis:

- Available resources, proven success using resources in CV PFS testing.

2.5.2.2 Step 5 – Guidance #5.2: Develop Local Approach to Off-line (Bench) Testing

Overview:

While traffic engineering groups in the IOOs are familiar with bench testing signal controllers, there may be less familiarity with bench testing the CI components. Therefore, the recommended next step in preparing for and accomplishing bench testing is to develop an agency approach to bench testing. Once this approach is agreed upon, a data collection plan can be created, the system configured in the test environment, and testing conducted.

Bench testing of CIs may accomplish one or more of the following:

- *Before CI deployment Functionality Tests.* Tests of the functionality of a signal controller, ECLA, RSU combination that the agency has not successfully deployed before. This could be testing for the first CI deployment of the agency, but also could be repeated with multiple RSU vendor products to increase the number of RSU options that the agency is comfortable procuring for future intersections.

- *Before CI deployment Situational Tests.* To test situations that would interrupt real-life intersections (signals going to all flash red, loss of power, regain of power) to understand how the SPaT message are output in these unique situations.

- *After CI deployment Troubleshooting.* To conduct very controlled tests when field deployments are found to be not functioning properly (e.g., if an intersection is not passing testing, it may be configured on the bench test environment to understand and debug it).

- *After CI deployment Firmware or Hardware Updates.* As new firmware is installed on the signal controller, an upgrade to the RSU is installed, or an updated MAP message is created, the CI functionality can be retested to ensure it is still functioning properly.

Bench testing typically involves the following components:

- Knowledge and skill set of the project team to perform data capture, execute automated utilities, and/or perform manual data analysis, as outlined earlier in Guidance 1.8.

- An operational but off-line TSC (i.e., not operating an intersection with public traffic) that is from the same signal controller manufacturer as used in operational intersection(s) with the current firmware that is operational at the field location where the system will be deployed, with the active signal timing plan operational.

- Any additional hardware or software included in or connected to the TSC that supports the SPaT message assembly and/or delivery to the RSU (referred to as the ECLA, as defined in the *CTI 4501 v01.01 CI Implementation Guide*).

- An RSU from the same manufacturer that will be deployed at the intersection with current firmware.

- An OBU to receive the broadcasted message, with wireline or wireless connection to a display device (laptop or tablet).

- The MAP message for the intersection that is being bench tested.

- Example RTCM message.

- Contracted relationship with SCMS provider and process in place to receive security credentials to be attached to SPaT and MAP messages at the RSU.

After a signal controller, ECLA, and RSU combination has been bench tested and found to be functioning, agencies may choose to not repeat bench testing with future intersections of the same combination. However, some testing is still likely to be performed at a minimum before installing new RSUs (e.g., testing that equipment powers successfully and connections are established). This will be described in more detail during deployment in Guidance #6.1 "Install Equipment in the Field".

<u>Guidance</u>:

- Using the Inventory in Guidance #2.1, the project team deploying the CI should already understand the signal controller and firmware version operational at the intersection. Use this information to work with traffic engineering to determine if this signal controller is replicated in an off-line environment and available for bench testing.

- The recommended approach to CI bench testing is to develop and maintain a bench environment of the TSC, ECLA, and RSU and to maintain this environment for the duration of the operation of the CI. This will allow tests of new firmware of the TSC, ECLA, or RSU in the future. Recommendations for when bench testing if performed are as follows:

    - *Field Equipment Test Before Deployment* – If possible, a bench test of the actual controller going to the CI, configured for that intersection, with the MAP message installed in the RSU should be bench tested and those equipment and files should then be deployed in the field. This process could be repeated for each intersection deployed as or converted to a CI.

    - *Version Upgrade Testing* – Each time a signal controller or RSU firmware is upgraded, a bench test should be conducted on either the exact equipment in the field or equipment that replicates those in the field.

- If the signal controller and current firmware are not replicated off-line, consider one of the following approaches:
    - Work with the traffic engineering department to determine if a bench environment can be established for this signal controller. Their experience with other bench test environments should support any questions about budget or timeline.
    - If it is not possible to replicate the signal controller in a bench environment, consider an alternate approach of communicating with other agencies that may already use (and have conducted off-line testing) the same hardware and software combinations. Testing results and lessons learned from those agencies may be leveraged, if appropriate.
    - Consider whether a bench test environment is needed or if your agency is comfortable performing all testing using the field installation.
- Because extensive field validation testing will be required regardless of the success of bench testing, agencies are encouraged to develop a bench testing program that produces useful information in balance with the more rigorous needs for field testing, and to automate the process as much as possible.
- Determine the testing to be performed in bench testing. The following are recommended tests during bench testing:
    - *SPaT Message Broadcast Periodicity* – Periodicity testing is used to determine if the RSU is broadcasting SPaT messages at 100 millisecond (ms) intervals. Testing of periodicity of SPaT Message is described more in the CAMP CI SPaT Assessment Procedure document, and once data is collected, this is an automated test that the CAMP utility can perform (i.e., difference in time between RSU broadcasts).
    - *SPaT Message Latency* – SPaT message latency is the time difference between the TSC generating SPaT information (i.e., TSCBM or NTCIP) to the broadcast of the SPaT message by the RSU. This includes communication of the data/message to the RSU, SPaT generation process time, message signing and broadcast. As per the CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide, this time shall be <300ms. This latency can be measured with the CAMP utility (i.e., difference between the time a SPaT message is created, and the SPaT message is broadcast by the RSU however this measurement would not include any delays between the output of signal timing data from the signal controller and the creation of the SPaT message).
        - *As noted earlier, the signal controller, ECLA, and RSU all need to be on the same time clock (UTC time)*. This is critical to measuring SPaT latency.

- *SPaT Message Creation Delay* – An element of the overall SPaT message latency that is difficult to measure is the SPaT message creation delay. This is the amount of time between an output from the signal controller and the creation of the SPaT message. This is more difficult to measure than SPaT Message Latency because it requires comparison of TSC data and the SPaT message creation time. The most critical interval change to test for basic RLVW is the onset of the Yellow Phase. Therefore, during bench testing, it is encouraged that IOOs test to determine the latency between the onset of Yellow Phase and the creation of a SPaT message reporting the Yellow Phase onset.

- *SPaT Message Accuracy Testing* – The Yellow Interval duration is a critical element of the SPaT message to RLVW applications. It is important that the time reported to be the end of the Yellow interval is accurate when it is broadcast at the onset of the Yellow interval and subsequent broadcasts. Therefore, if there are inaccuracies in this element, they should be identified during the bench testing. Currently, the CAMP utility, with manual processing by CAMP, is able to test this, but efforts are underway to automate this testing in the CAMP utility.

- *SPaT Message Format Testing* – SPaT message format testing will determine if the SPaT message conforms to the requirements of a valid SAE J2735 SPaT message and if all the required elements of the SPaT message are included. Once data is collected, this can be tested with the CAMP utility.

- *MAP Message Format Testing* – MAP message format testing will determine if the MAP messages conform to the requirements of a valid SAE J2735 MAP message. Details of MAP message format testing are contained in the CV PFS CI Test Plan and make use of the CAMP Analysis tool.

- *SPaT/MAP Message Alignment* – This testing will determine if the signal groups in the SPaT message are aligned with the signal groups in the MAP message. The MAP message indicates the signal group assigned to each connection and allows the in-vehicle application to understand which signal group in the SPaT message is controlling their movement. If these are not aligned correctly, in-vehicle applications will be interpreting the wrong signal group and therefore the wrong signal indication. If misalignment of these occurs, it is not a hardware or software issue, but a human error when either interpreting the SPaT message or in configuring the MAP message or both. If this aspect is tested during bench testing, it most likely would not need to be re-tested in field validation.

- *RTCM Message Format Testing* – During bench testing, a sample RTCM message (from the selected source) can be tested to determine if it meets the formatting requirements of SAE J2735.

<u>Basis</u>:

- Recommend these seven tests in the bench testing to avoid more time consuming and costly testing in the field.

2.5.2.3 Step 5 – Guidance #5.3: Assemble and Configure the Off-line (Bench) Test Environment

Overview:

Ideally, agencies beginning to deploy CIs can use already available bench test facilities and resources for conducting bench testing. The checklist provided in Documentation 3.7 may be used to generally understand what is needed for off-line testing but should be customized as part of data collection plan development in Guidance #5.2.

The off-line testing environment is expected to reasonably replicate the hardware, software, and network configuration typical of the deployed environment for message content testing (see CI Test Plan Section 6.2). The test plan and bench test preparations described in Guidance #5.1 and #5.2 should be used to assemble and configure the equipment in a way that replicates how it will be deployed in the field as closely as is possible in the laboratory environment.

FHWA has produced a Connected and Automated Vehicle Education (CAVe) training video on RSUs that is available on YouTube. While practitioners should follow instructions from the RSU provider for setting up and configuring an RSU, the information presented in this video may help practitioners understand what needs to occur in this step (e.g., need for a power over ethernet (POE) injector, connecting antennas to the RSU).

Guidance:

- Ensure the facility where bench testing will occur includes all the items recommended in the Documentation 3.7 checklist.
- Assemble all the "typical equipment" recommended in the Documentation 3.7 checklist, as needed for the tests to be conducted based on the outcome of Guidance #5.2.
- Connect the RSU to the power over ethernet (POE) injector and to the ECLA or signal controller, as appropriate.
- Note that the RSU typically requires GPS access to operate. Therefore, the RSU must have access to the sky, either mounted outdoors or in a location that has access to satellites. This can be challenging when working in a bench test environment.
- Establish the SCMS credential signing as it will be in the field (e.g., likely the RSU will apply credentials).
- Connect a computer to the RSU and perform any configurations of the RSU to replicate the planned configurations for the field. Specifically, note the following:

- Ensure that the time source of the signal controller, ECLA, and RSU are configured as they will be in the field. It is recommended that the time source of each be network time protocol (NTP) server.

- Load the required MAP messages (e.g., to the RSU if appropriate).
- Load in a sample RTCM message to the RSU.
- Ensure all components are powered on and activate the signal controller to begin.

Basis:

- Bench environment is needed. Typical equipment based on CV PFS CI Test Plan.

2.5.2.4 Step 5 – Guidance #5.4: Collect Data for Off-line (Bench) Test

Overview:

Figure 10 illustrates the flow of data from the signal controller, conversion to SPaT messages, communication to the RSU, and eventually broadcast by the RSU following two optional paths (Path 1 illustrates the situation when data is communicated directly from the TSC to the RSU, Path 2 illustrates the situation when data is communicated from the TSC to an external processor, and then to an RSU). Off-line testing is recommended to include collecting data samples at Point A (the actual signal controller values sent to the signal indicators), the output from the RSU (either Point C if no ECLA is used (Path 1) or Point E if an ECLA is between the signal controller and the RSU (Path 2), and data collection by an OBU receiving the over-the-air message). Ideally, an OBU is available to collect this information as it is broadcast, but as an alternative data could be collected from Point B (Path 1) or Point D (Path 2).

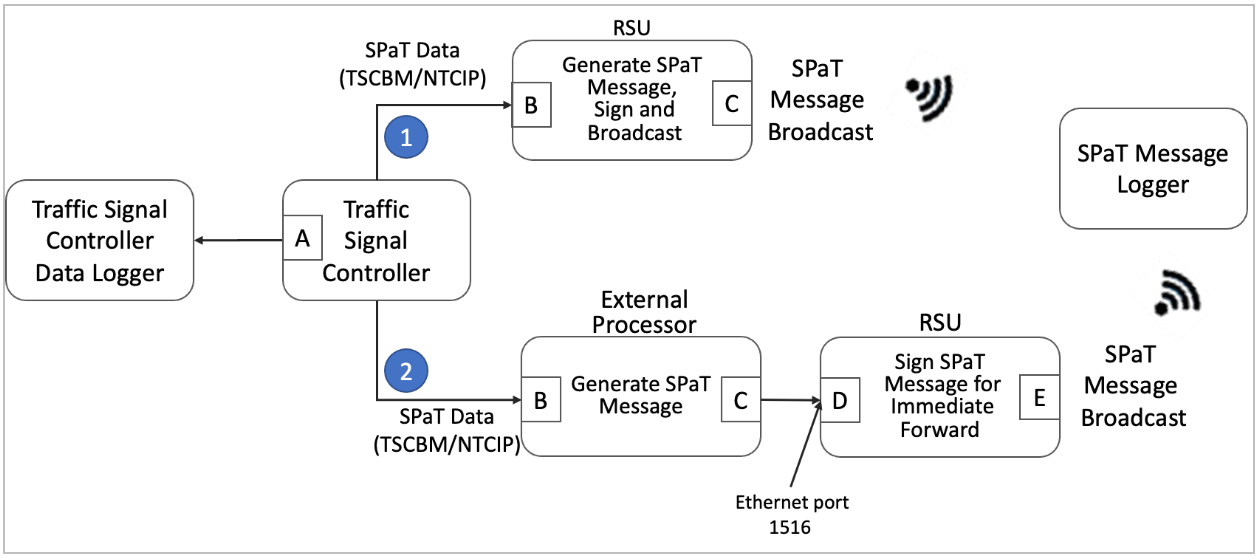
A general description of bench test data collection is as follows:

- Signal Controller (Point A). Some signal controllers have their own output and reporting capabilities (typically CSV files) and some signal controllers output data using the Advanced Traffic Signal Performance Measures (ATSPM) software connected to the signal controller. Either of these (or alternate approaches) need to be established to capture and record signal controller data.

- RSU Output (Point B or D). RSUs typically contain an ethernet port that is different from the broadcast port. At the time messages are sent to the broadcast port, they are sent to the ethernet port. By connecting to this ethernet port, off-line testing activities can record data at the RSU output. Tools such as Wireshark can be used to capture data as PCAP file.

- OBU capture of broadcast messages. OBUs typically contain a port that Wireshark data captures can be connected to and save PCAP files.

- The file collected at the RSU output will have the content required for the CAMP Utility (Version 1) to process the data and report on SPaT and MAP message format, and on SPaT broadcast latency (difference in time from message creation to message broadcast).



Source: CAMP SPaT Accuracy Assessment Procedure

Figure 10. Illustration of data flows from the signal controller, conversion to SPaT messages, communication to the RSU, and eventually broadcast by the RSU.

<u>Guidance</u>*:*

- Compare time sources of the RSU, ECLA, and TSC to determine if they are on the same time (UTC time).
- Using local capabilities, establish a data collection method to collect the signal controller data (i.e., using ATSPM or data exports inherent to the signal controller) (Point A). Collect and if necessary, convert the data to CSV files.
- Operate an OBU to receive message broadcasts and capture OBU data using a Wireshark connection (at Point C in Path 1 or Point E in Path 2, represented as SPaT Message Logger in Figure 10). Establishing a connection with an OBU is preferred; however, if it is not possible to use an OBU a connection can be established at the message broadcast port of the RSU at Point C (Path 1) or Point E (Path 2) to capture and log PCAP information.
- Operate the overall system for a time period of multiple signal cycles, capturing the PCAP files at the RSU.
- Collect data describing the signal control group represented in the SPaT message to compare with the MAP message to test if the signal groups align. This will determine if in-vehicle

applications receiving and processing MAP messages would properly identify the correct signal group.

- After collecting the above data for normal operations, perform a series of tests of unusual situations that would not be replicated in the field, such as:
  - Setting the signal controller to all flashing red;
  - Powering down the signal controller and powering up;
  - Powering down the RSU and powering up; and
  - Uploading a revised MAP message.
- Capture all SPaT/MAP PCAP files and convert to JSON files. Note that the CAMP tool only converts J2735 message PCAP files to JSON for processing.

Basis:

- Required data per CV PFS CI Test Plan.

2.5.2.5 Step 5 – Guidance #5.5: Analyze Off-line (Bench) Test Data

Overview:

Bench testing of the SPaT messages are expected to be conducted using the on-line utility outlined above and should not require manual analysis of data.

Guidance:

- Upload the converted JSON files that were recorded in the previous step to the CAMP developed utility. Note that additional information on the use of the CAMP utility are available in the *CTI 4502 v01 CI Validation Report*.
  - *SPaT Message Generation Periodicity* – As SPaT messages are uploaded to the on-line utility, the utility will report the time that the SPaT message was created, allowing an understanding of the SPaT message generation periodicity. The periodicity should be as close to 100 ms as possible (preferably 90=110 ms range). A final determined acceptable tolerance level has not yet been established.
  - *SPaT Message Transmission Latency* – The on-line utility will report the difference between the message creation time and RSU broadcasts time. The latency of internal SPaT message communication to RSU broadcast should not exceed 300 ms.

- *SPaT Message Accuracy Testing* – A process to upload the signal controller data and the data collected at the RSU should be followed using the on-line utility developed by CAMP.

- *SPaT Message Format Testing* – The on-line utility will report the SPaT message conformance to the SAE J2735 standard and identify any values outside the expected bounds. Additional details and an example about conformance and the use of this tool are available in the *CTI 4502 v01 CI Validation Report*.

- *MAP Message Format Testing* – The on-line utility will report the MAP message conformance to the SAE J2735 standard. The on-line utility will also allow a visual view of the MAP message. Review this view to determine if all approaches and lanes are represented. Additional details and an example about conformance and the use of this tool are available in the *CTI 4502 v01 CI Validation Report*.

- *RTCM Message Format Testing* – There is no known tool for verifying RTCM message format at this time. More detail on RTCM v3.3 message types and frequency is provided in the *CTI 4501 v01.01 CI Implementation Guide*.

Basis:

- Recommended use of proven effective tools.

2.5.3 Summary and Outcomes of Step 5

Upon completing Step 5, practitioners should have completed bench testing activities in an off-line laboratory environment and be ready to deploy CI system components and configurations for additional validation in the field, as part of Step 6.

2.6 STEP 6 – DEPLOYMENT AND FIELD VALIDATION

Step 6:
Deployment and Field Validation

The goals of Step 6 are to deploy, configure, and make the CI components operational and then to conduct field validation. During Step 7, each CI will need to be verified by an approved process for security credentials to be trusted by OEM RLVW applications. Each IOO will need to decide if all CIs deployed are subject to the detailed validation described in Step 6 or if multiple intersections are deployed with identical components, the IOO may trust that validating a subset of the intersections is adequate. Therefore, field validation testing is recommended for all new equipment after it is deployed in the field and before it is subject to vehicle verification, but IOOs may use their discretion on this. Field validation testing on operational intersections will allow the deploying agency to confirm the actual operation and performance of the specific intersection and to verify that the system is correctly configured for the specific intersection. Note that earlier guidance suggested testing this in the bench test environment as it is preferred to discover any of these issues before field deployment. If tested in the bench environment and the same equipment and messages are deployed to the field, configuration testing may not be needed in the field. For example, validation will need to confirm:

- That the correct MAP message for this intersection is installed.
- That the signal groups correctly relate the SPaT information to the proper movement shown in the MAP message.
- That SPaT messages broadcast are complete, properly formatted, accurate representations of the intersection status and are being broadcast at a periodicity of 100 ms.
- That RTCM messages are being broadcast by the RSU at a frequency that is in the range of 1 to 5 Hz (see Section 1.2.1 for more details).
- That the MAP messages are being broadcast by the RSU at a periodicity of 1000 ms.

Field validation should be conducted by the IOO that operates the intersection with support from contractors and signal control manufacturer, as needed.

After successful field validation, Step 7 will be Vehicle Verification of the intersection, where connected vehicles will drive the intersection and collect data reporting on the ability of the intersection to provide the periodicity, accuracy, precision, and formatted messages for RLVW applications to operate properly.

2.6.1 Objective

The goal for Step 6 is to help practitioners to understand:

- The need for validation and what needs to be validated.
- The resources available and what staffing, equipment, and actions they should expect to do.
- How to perform field validation by using the resources described in this section.

By following the guidance in Step 6, practitioners should understand the role of field validation, and be able to develop a local approach for testing all CI requirements using a combination of bench testing and field validation that makes the most sense for the local conditions, constraints, and available resources.

2.6.2 Step 6 Guidance

CI deployers are encouraged to deploy and test the procured system in the field as outlined in Table 13 below during Step 6. While this guidance encompasses the testing of requirements specified by the *CTI 4501 v01.01 CI Implementation Guide*, CI deployers have some flexibility in testing each requirement either in the field or as part of bench testing. Deployers should consider local constraints, available resources and equipment, and any additional local applications or requirements that may be desired (e.g., transit signal priority) for testing in either the bench test environment, as part of field validation, or both.

Table 13. Step 6 – Deployment and Field Validation: Guidance List

Step 6 – Deployment and Field Validation		
	Guidance #6.1	Install Equipment in the Field
	Guidance #6.2	Download and Familiarize with Resources to Support Field Validation
	Guidance #6.3	Determine Staffing and Equipment Approach to Field Validation
	Guidance #6.4	Develop Local Data Collection Plan for Field Validation
	Guidance #6.5	Collect Stationary Observations and Drive Through Deployed Connected Intersection to Gather Data
	Guidance #6.6	Complete Requirements Validation Tests
	Guidance #6.7	Complete Supplemental Validation Tests (Broadcast Periodicity and Yellow Interval Duration)
	Guidance #6.8	Collect and Analyze Data to Validate MAP Message Content
	Guidance #6.9	Make Changes to Correct Errors and Retest

2.6.2.1 Step 6 – Guidance #6.1: Install Equipment in the Field

Overview:

During Step 6.1, equipment procured as part of Step 4 is installed at the intersection according to the system architecture and design developed as part of Steps 2 and 3. Installation of the intersection is seen as a separate step from validation of the system functionality, although minimal testing to verify basic functionality (e.g., power and connectivity to devices) is recommended.

At the conclusion of Step 6.1, the components of the CI should be installed and operating on a continuous basis.

Guidance:

- Installation should generally follow the same hardware, software, and network configurations that were used during the bench testing for this combination of equipment.
- Regardless of whether installation is done by a contractor or the agency, each installation should be overseen by staff with specific training or qualifications as required locally (e.g., licensed professional engineer, licensed electricians, use of adequate traffic control to enable safe access, etc.) as would be done with any work at the intersection.
- Refer to outcomes of earlier guidance (Documentation 1.7 and 1.8) to identify any infrastructure changes (e.g., cabinet space, power, connectivity) that are needed to be added to the intersection to either support operations of the CI or the validation process.
- Follow agency-required construction requirements to as agency staff or procured contractors install the RSU and supporting equipment and communications specified in Step 3.
- Some basic checks should be performed before taking the new equipment to the field, such as:
    - Performing limited tests of RSU functionality (e.g., Able to power on? Able to power off? Able to establish communications? Able to send commands to the RSU to pause SPaT/MAP broadcasts). As per the *CTI 4001 v01 RSU Standard*, the communication between the back office and the RSU using the SNMP V3, RSU can be remotely controlled to stop SPaT/MAP broadcast.
    - Configuring the RSUs (e.g., In deployments where the signal system outputs J2735 SPaT messages or an ECLA assembles the messages, RSUs are typically configured to perform “immediate forward” of SPaT messages. In deployments where the data is not sent to the RSU as a J2735 message, the RSU converts TSCBM or NTCIP 1202v3A into J2735 SPaT messages. Typically, RSUs are configured for “store and repeat” of MAP messages stored at the RSU).
    - Final configuration of the ECLA.
- Perform construction of any supporting mechanism and mount field equipment and communications as per the agency-required construction plans defined above.

- Provision the RSU with security certificates unless previously accomplished.

- Upload the MAP message to the appropriate location (e.g., RSU or ECLA) as defined in earlier steps.

- Install the ECLA (which might be software only or might be software and hardware) and establish connection to the signal controller.

- Install the RSU and establish connection to the ECLA (or signal controller).

- Confirm power and communications to all equipment.

- Confirm synchronization of time sources in UTC (not local time). The recommendation is to configure the signal controller, ECLA, and RSU to use NTP server time source if available.

Basis:

- Use of local practices and resources from earlier steps.

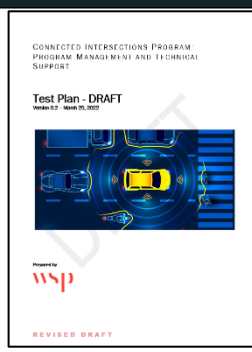
2.6.2.2 Step 6 – Guidance #6.2: Download and Familiarize with Resources to Support Field Validation

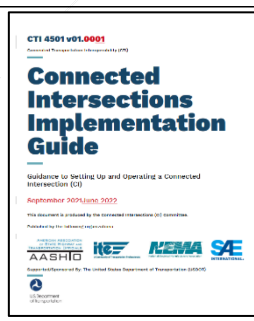
Overview:

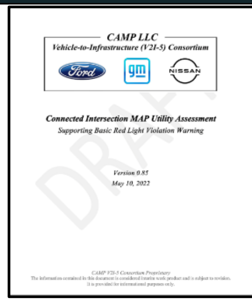
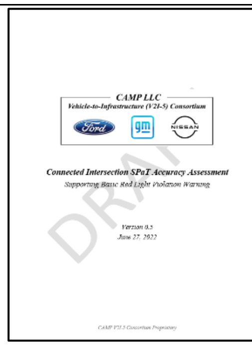
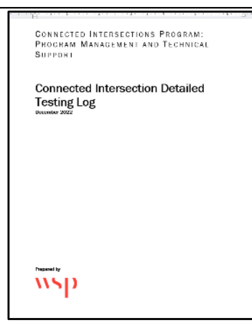
Field validation testing should test all required fields outlined in *CTI 4501 v01.01 CI Implementation Guide*. There are a considerable number of requirements to test. However, there are several test plans, resources, and validation utilities that have been created to support local field validation. These include the eight resources described in Table 14.

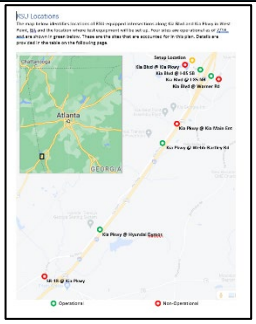
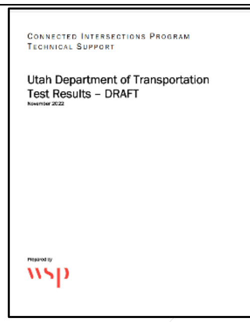
Table 14. Resources to Support Field Validation.

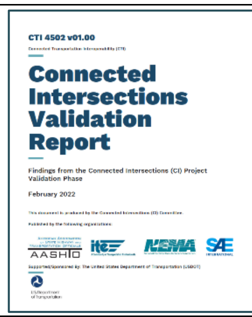
Resource and Summary	Key Contents	Relationship to Field Validation

CI Test Plan. Comprehensive test plan to test for basic RLVW functionality. Test activities exclude a limited set of requirements not related to basic RLVW and may not fully test CIs for all OEM applications. This document describes CI test activities completed for Ohio, Georgia, and Utah. 
 	
Readers may use this to inform their testing activities or adapt this to their local situation.
 	
Source: CV PFS. Available at this link.
	- Items to be tested
	- Test Site Activities
	  - Test Roles
	  - Test Tools
	- Test Environment
		120 test case tables defining what needs to be tested for all requirements. Each includes:
		- Test design detail
		- Description of test
		- Data collection type
		- Evaluation methodology

CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide. Provides details about signal controller requirements to satisfy basic data needs for RLVW applications.  Source: ITE. Available at this link.	The NRTM identifies the requirements that are mandatory, conditional, or optional.	Provides additional details of each requirement that may be useful when preparing for and conducting testing.

Resource and Summary	Key Contents	Relationship to Field Validation
CI MAP Utility Assessment Supporting Red Light Violation Warning. Describes an available on-line utility that can be used to test MAP message format and MAP accuracy if accompanied by drive data collected by and OBU.  CAMP LLC Vehicle-to-Infrastructure (V2I-5) Consortium Connected Intersection MAP Utility Assessment Supporting Basic Red Light Violation Warning Version 0.85 May 10, 2022 Source: CAMP LLC. Version 0.90 August 16, 2022 available at this link.	- Description of the online MAP utility - Description of how to use the MAP utility to test MAP format and MAP accuracy	- Document describes the use of the CAMP utilities. - CAMP utilities defined in another resource below.
CI SPaT Accuracy Assessment. Describes the data collection and analysis for two key items critical to success of RLVW applications: Yellow phase duration accuracy and SPaT transmission periodicity.  CAMP LLC Vehicle-to-Infrastructure (V2I-5) Consortium Connected Intersection SPaT Accuracy Assessment Supporting Basic Red Light Violation Warning Source: CAMP LLC. Version 0.9 September 28, 2022 available at this link.	Describes: - Basis for assessment - Data collection activities - Data analysis activities For both yellow phase duration accuracy and SPaT transmission periodicity.	Yellow light duration and SPaT transmission periodicity are critical to later vehicle verification. Conducting detailed analyses of these will allow agencies to identify and correct any deficiencies.
CI Detailed Testing Log. Describes the validation methodology recommended to test each requirement, together with designated space to enter results and explanation as testing is conducted.  Connected Intersections Program: Program Management and Technical Support Connected Intersection Detailed Testing Log Source: CV PFS. Available at this link.	120 tables identifying all requirements to be tested, method of testing each, and results and explanation	A template that agencies can customize and complete their "results and explanation" as they test. A completed version prepared during CV PFS testing in Utah is available as part of the Utah DOT Test Results Report.

Resource and Summary	Key Contents	Relationship to Field Validation
Utah Data Collection Plan. A brief, informal document used to describe data collection activities to ensure the staff collecting data in the field gather all the needed data and have pre-defined routes of travel and static data collection locations.  Product of the CV PFS. Available at [this link].	Identifies: - Intersection/RSU locations to be validated - Approaches where video capture will be performed - Driving routes and static data collection sites - Ground survey plans - Schedule of activities	This resource, in conjunction with the CI Detailed Testing Log and Test Plan, provides an example that individuals planning data collection can reference or modify (e.g., by inserting their own aerial imagery and defining local locations and testing activities).
CI Utah DOT Test Results Report. Comprehensive report describing the tests performed and results, including areas for improvement for requirements that were either partially met or not met.  Connected Intersections Program Technical Support Utah Department of Transportation Test Results – DRAFT wsp Product of the CV PFS. Available at [this link].	Includes detailed results for all tested requirements at all tested CIs, as well as summary remarks and discussion	Provides an example for how test results may be reported for an agency to validate CIs and make necessary improvements to fully meet all requirements.
CAMP SPaT/MAP Utility, version 1. On-line tool that allows the upload of JSON files and processes them to analyze SPaT and MAP messages. Analyses include: • SPaT message format: Are all required fields populated and values within allowable bounds? • MAP message format: Are all required fields populated? • SPaT broadcast periodicity.	- On-line utility - Described in related documents prepared by CAMP	Data collected at the RSU output or OBU can be captured as a PCAP file, converted to JSON, and uploaded to this utility. The utility will provide analysis, some automated today, other analyses require manual actions but are intended to become automated.

Resource and Summary		Key Contents	Relationship to Field Validation
Additional details about use of this Utility are available in the *CTI 4502 v01 CI Validation Report* listed below. Source: CAMP, developed in Ann Arbor project, enhanced during ITE/CI validation. On-line access is not currently available, but a report summarizing this is expected to be posted to the CAMP LLC website at: https://www.campllc.org/publications/.			
CTI 4502 v01 Connected Intersections Validation Report. Summarizes findings from the 2021 ITE CI project validation phase. Source: ITE. Available at [this link]().	 CTI 4502 v01.00 Connected Intersections Validation Report Findings from the Connected Intersections (CI) Project Validation Phase February 2022	Describes data collection and analysis for field validation, including information about the CAMP tools used to verify SPaT and MAP messages.	Describes field validation processes conducted by ITE CI project, as well as additional details for using the CAMP SPaT/MAP Utility.

Guidance:

- In early guidance sections, you should already have downloaded the *CTI 4501 v01.01 CI Implementation Guide*, developed by ITE. Review this document, as needed, for specific questions about the CI requirements.
- Download and familiarize yourself with the CI Test Plan document.
  - Carefully review Chapter 6 to understand test site activities related to field testing to understand:
    - Testing Approaches;
    - Test Roles;
    - Schedule; and
    - Test Tools.
  - Review the Test Cases described in Chapter 8. Note that the test cases in Chapter 8 are also included in the CI Requirement Validation document.

- Download and familiarize with the CI Requirements Validation documents (note: completed documents from Ohio, Georgia, and Utah are resources to support completing the template version).
- Download and familiarize with the CI SPaT Accuracy Assessment document.
- Locate and become familiar with the CAMP developed Utility for SPaT/MAP message assessment. Note that additional information on using the CAMP Utility is available in the *CTI 4502 v01 CI Validation Report*.

Basis:

- Available resources, proven success using resources in CV PFS testing.

2.6.2.3 Step 6 – Guidance #6.3: Determine Staffing and Equipment Approach to Field Validation

Overview:

Based on the outcome of the Documentation 3.7 Checklist and review of resources in Guidance #6.2, each agency preparing to validate their CIs should make decisions about their approach to accomplishing the field validation. The CI Test Plan and other supporting resources reviewed in Guidance #6.2 provide detailed explanations of the required skills and estimates of the time required. Specifically, each site should determine:

- *Staffing resources.* Does the agency have the skills, experience, and staff time to dedicate to perform the field validation in-house or with existing contractors or will field validation services need to be procured?
- *Equipment availability.* Are additional equipment required to support field validation testing?
- *Access to on-line utilities.* The on-line utilities require access and an understanding of the required data formats required to properly use the on-line utilities.

Guidance:

- Review Chapter 6 (General Test Site Activities) of the CI Test Plan to understand the operational testing approaches, roles to be performed, the recommended schedule of activities, and the steps to perform message content testing and message format testing. Review the test cases outlined in Chapter 8 of the CI Test Plan to understand the analysis to be conducted on the data collected.
  - Based on this review, determine if agency staff have the skills and availability to perform the data collection and analysis.

- If it is determined that contractor support will be required for field validation, the five resources outlined in Guidance 6.2 can be used as the basis for a solicitation for support services.

- Review the Documentation 3.7 Checklist and Section 6.5 (Test Tools) of the CI Test Plan to understand the equipment required to perform field validation.

Basis:

- The CV PFS Test Plan includes detailed descriptions of processes to perform testing.

2.6.2.4 Step 6 – Guidance #6.4: Develop Local Data Collection Plan for Field Validation

<u>Overview</u>:

In order to complete all data collection adequately, safely, and efficiently, it is recommended that a Data Collection Plan be developed to describe the approach for collecting the needed data. Figure 11 notes data collection approaches in order to conduct various tests, as well as some alternative data collection approaches, which may be pursued based on local conditions and the selected testing approach. This Guidance #6.4 describes the data collection approach in the CI Test Plan; information about supplemental validation tests are described in more detail in Step 6 – Guidance #6.7.

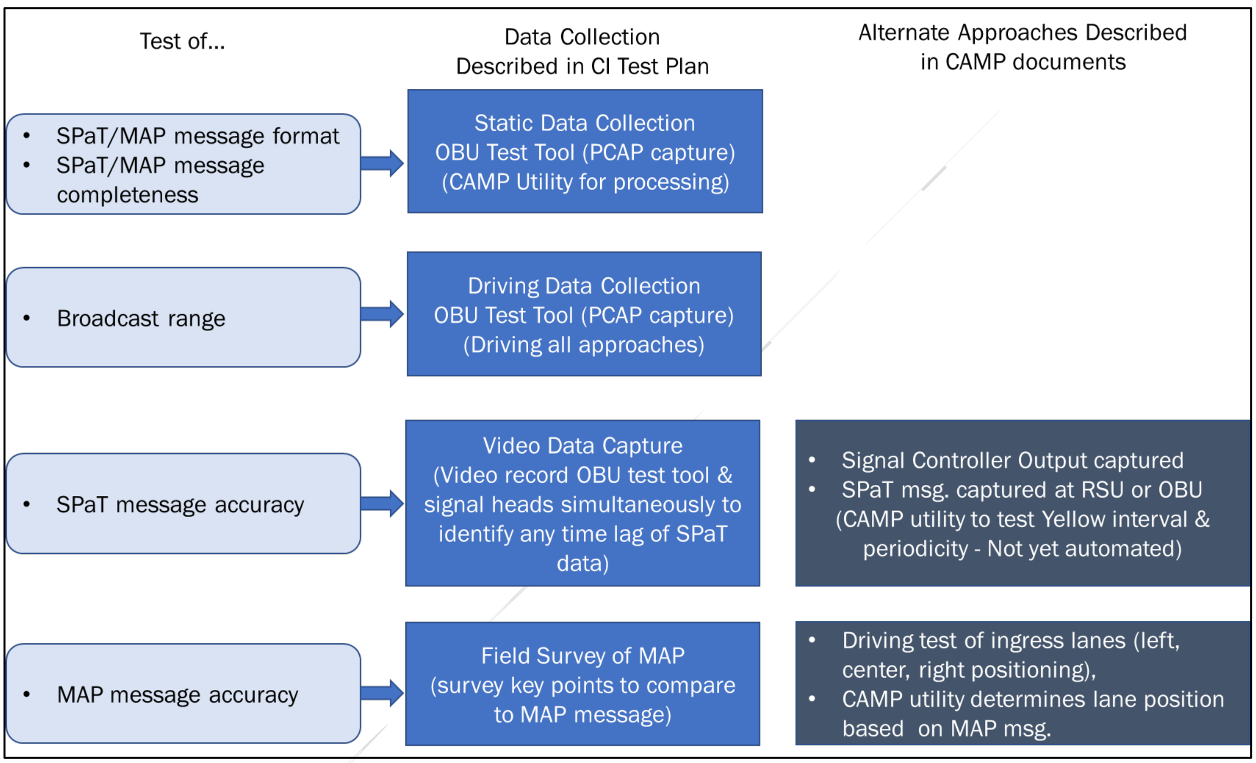


Figure 11. Data Collection Approaches to Conduct Various Tests.

The data collection needed for field validation testing will involve the following:

- The capture of SPaT messages either received by an OBU or at the point where the RSU is broadcasting the data (i.e., data port), to be used both to test the SPaT message conformance and message completeness and (optionally) to be used in comparison with the signal controller data to test the SPaT message accuracy and the periodicity of messages. In situations where the SPaT messages are captured where the RSU is broadcasting data, the collection process is like the bench testing, except the RSUs are in the field.

- The capture of MAP messages to test the MAP message completeness and compliance.

- If field surveys are conducted, the field measurement of actual positions (latitude, longitude, elevation) of key elements of the MAP message (e.g., node points, lane widths, etc.), to be compared with the data comprising the MAP message.

- If SPaT message accuracy and periodicity testing involve comparisons to signal controller data, the capture of signal controller data as output by the signal controller will need to be collected. The goal is that the SPaT messages received by OBUs accurately describe the signal controller head displays.

- The capture of RTCM messages to test RTCM message compliance.

Most measurements for field testing can be performed using the following:

- *Over-the-air message capture.* These would be testing tools that involve an OBU device that allows for message receiving, storing, receiving, and access. These captures can be used to perform the capture of SPaT messages, MAP messages, and RTCM messages. These will support testing of message completeness and accuracy, as well as testing RSU broadcast range.

- *OBU visualization tools (e.g., Kapsch Tool, originally developed by e-trans for CAMP).* These include tools (e.g., iPad display, laptop, or other) that when connected to an over-the-air-message capture allow for visualization of the MAP message and SPaT data received. For example, this can be observed to understand when an approach transitions from one interval to another.

- *High-frame rate cameras.* Cameras that could be used to visually observe and note the time when a signal head transitions from one interval to the next.

<u>Guidance</u>:

- Download the Data Collection Plan(s) available at the CV PFS website (as described in Guidance 6.2) and use the MS Word documents to edit and create a local Data Collection Plan for the site. Specific edits to the data collection plan template should be based on the following:

  - *RSU Locations.* Replace the contents of RSU location with a map image of the locations of the intersections to be tested, indicating the operational status of the RSU.

  - *Video Data Collection.* Using Google Street View, identify and capture pictures of each signal head to be captured during video collection. Supplement the pictures with arrows or boxes to call attention to signal heads and movements. It is important to capture all movements in these images to remind data collectors of all states to be captured in video (e.g., through, left-turn protected, left-turn permissive).

- *Data Collection Driving Routes and Static Data Collection Sites.* Replace this section with an appropriate aerial view images of each intersection planned for testing. Place graphics/icons to illustrate:
  - Static Data Collection Sites. Locations where the vehicle will stop and allow testers to capture video of the signal head and in-vehicle OBU.
  - Driving routes. Planned movements to collect PCAP data. Driving routes should travel far enough away to test the boundaries of coverage of the RSU broadcast.
- *Ground Survey.* Replace the text in this section to describe local ground survey plans, if any. If a ground survey is planned, indicate what data is to be captured. The following are recommended:
  - Location of the center of both lane edge lines at the upstream intersection with the stop line for each ingress lane surveyed.
  - Location of center of both lane edge lines at a location approximately 100 meters upstream of intersection for each ingress lane surveyed.
- *Schedule.* Replace schedule text with the plan for data collection. Use the example allocations of time durations to base estimated times.
- *Signal Controller Data.* Enter a description of how the signal controller data will be collected from the controller (if it is captured). The capture of signal controller data as output by the signal controller will be used to test the SPaT message accuracy and the periodicity of messages.

• As part of the data collection plan, ensure that all necessary equipment is available, as described in the Documentation 3.7 Checklist and Section 6.5 of the CI Test Plan, including the following:

- Over-the-air Message Capture:
  - On-Board Unit (OBU) and vehicle to capture CV messages for message completeness, accuracy, and broadcast range testing and troubleshooting.
  - Open-source Wireshark Packet Analyzer software to capture data when connected to the OBU.
- OBU Visualization Tools:

    - A high framerate camera and associated software (e.g., GoPro Hero 9 camera and GoPro player) will be used to respectively capture high framerate video, and then review and reframe it.

- Software tools for MAP validation (e.g., CAMP Tools or ESRI ArcGIS tools).

- Survey equipment or a survey team for MAP validation.

Basis:

- Field data collection plan will help prevent missed data collection and avoid multiple field visits.

2.6.2.5 Step 6 – Guidance #6.5: Collect Stationary Observations and Drive Through Deployed Connected Intersection to Gather Data

Overview:

Field validation data collection will perform the activities outlined in the Data Collection Plan. Most operational field validation tests will use data that is collected from a vehicle with an OBU connected by a Wireshark connection to a laptop computer or iPad to capture data and a video camera to visually observe the signal head display. A combination of stationary data collection and active drives will be performed to collect the data. At least two members are recommended to be in the vehicle to perform these tests, one to perform the driving duties and the second to operate the test equipment. Figure 12 shows stationary observations being conducted at a CI in Utah.

Key resources for this step include the CI Test Plan, sections 6.1.2 and 6.2 and the Data Collection Plan prepare in earlier steps.

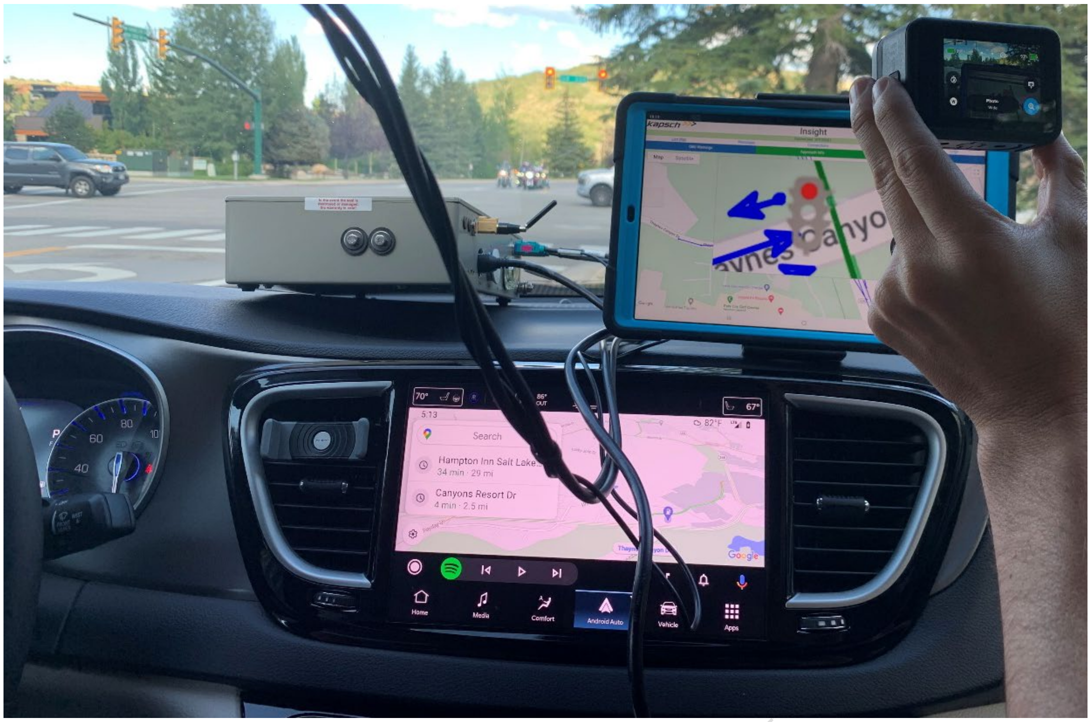


Figure 12. A High-Resolution Camera Captures the Time that the Traffic Signal Head Display Changes versus the Change Displayed on the User Interface based Receipt of Signal Phase and Timing Messages through the On-Board Unit in Order to Determine Latency

<u>Guidance</u>:

- Assemble all the equipment described in the Data Collection Plan and in the CI Test Plan.
- Determine if there is a need to notify others in your agency or neighboring agencies about the intent to collect stationary and driving data collection during the planned days.
- Conduct preliminary (quick) check through visualization that the signals viewed match what is displayed on the OBU. This could identify any basic errors (e.g., N/S indicators being switched with the E/W indicators, MAP from wrong intersection installed, etc.). This brief test could allow errors to be corrected before conducting the detailed data collection.
- Conduct test data collections, both static and driving, with the OBU/Wireshark combination and camera to ensure data is collected and stored appropriately.
- Follow the directions in the CI Test Plan and execute the Data Collection Plan.

<u>Basis</u>:

- Required data collection to execute CV PFS CI Test Plan.

2.6.2.6 Step 6 – Guidance #6.6: Complete Requirements Validation Tests

Overview:

After conducting the stationary observations and drive through testing, the data collected should be adequate to complete the CI Requirements Validation tests. These validation tests are created to test the requirements described in *CTI 4501 v01.01 CI Implementation Guide*.

Four key resources (described above in Table 14) are available to support this step:

- *CV PFS CI Test Plan* (developed by WSP). Specifically, Chapter 8 – Test Cases that include a subsection for each requirement, describing the requirement, evaluation methodology, and system inputs and outputs.
- *CV PFS CI Requirements Validation – Template.* This is a template of tables for each requirement that can be used to complete the findings of each test executed.
- *CV PFS CI Requirements Validation – Ohio Example*. This is a completed document describing the validation tests completed for each requirement in Ohio, to be used as an example of how to document results.
- *CV PFS CI Requirements Test Methods Spreadsheet.* This is an Excel document containing each requirement, and information about testing and validating each requirement. This may be used if spreadsheet format is preferred during data collection.

Guidance:

- Assemble all data collected during the stationary observations and drive through testing. This should include:
  - PCAP files collected during the stationary testing and drive testing.
  - Signal Control data files captured and recorded during data collection.
  - Video captured of signal control heads and OBU display.
- Using the CV PFS CI Detailed Testing Log, proceed through each requirement table, executing the "method" described to assess each requirement.
  - Refer to the completed example from the Utah Connected Intersection Test Results to guide your analysis and completion of steps.
  - Refer to the CV PFS CI Test Plan and CI Requirements Test Methods Spreadsheet for additional details on each requirement.
- In the "Results and Explanation" cells, record the findings of each test activity, using examples from other documents as references.

Basis:

- Validation test method successful in CV PFS sites.

2.6.2.7 Step 6 – Guidance #6.7: Complete Supplemental Validation Tests (Broadcast Periodicity and Yellow Interval Duration)

Overview:

The requirements validation tests described in Guidance 6.6 (together with the resources described in Guidance 6.6 are considered the primary validation approach in this guide. However, supplemental validation tests may also be completed, as described in this step.

The validation of SPaT broadcast periodicity and the SPaT message accurate representation of yellow interval duration are critical to ensuring a CI is valid and ready for verification. For this reason, supplemental validation tests are described to be performed to test these elements. The resource introduced above titled "CI SPaT Accuracy Assessment Procedure" developed by CAMP describes a step-by-step approach to testing yellow phase duration and SPaT broadcast periodicity.

Note that SPaT broadcast periodicity is represented in the CV PFS CI Test Plan and Requirements Validation as Requirement 3.3.3.1.5.1.

As the industry is still developing and finalizing validation procedures, this supplemental step is recommended for consideration.

Note that the yellow interval duration is represented in the CV PFS CI Test Plan and Requirements Validation as Requirement 3.3.3.3.5.3.3 (Minimum End Time). Again, this supplemental test offers a different perspective and approach using an alternate tool.

As more experience is gained with testing and validation of CIs, these supplemental tests may not be needed (the tests in the CI Test Plan may suffice) or these supplemental tests may replace those in the CI Test Plan. For the time being, the value in both is recognized and both are recommended.

Guidance:

- Use the resource identified above (CI SPaT Accuracy Assessment Procedure) to conduct the data collection and data analysis to test both the yellow phase duration and the SPaT broadcast periodicity.
- The data to support this should have already been collected during earlier data collection. However, additional supplemental capture of data from the RSU or OBU might be needed, together with concurrent collection of signal controller data.
- At this time, data collected must be manually processed by CAMP, but the intent is that the Version 2 Utility would be modified to perform this analysis automatically, pending funding availability.

Basis:

- Developing process to verify SPaT message quality, believed to eventually be needed for CI verification.

2.6.2.8 Step 6 – Guidance #6.8: Collect and Analyze Data to Validate MAP Message Content

<u>Overview</u>:

The MAP message content refers to the accuracy of the node points that make up the MAP message. There are at least two methods for assessing the MAP message content:

- *Method #1 (Described in CI Test Plan): Field survey to collect actual lat/lon/elevation data.* As outlined in the CI Test Plan, an onsite survey of key points can be conducted and from key points centerline node points can be derived and compared to the MAP message values. Also, field survey observations can identify horizontal curves and survey to determine if adequate node placement exists.

- *Method #2 Vehicle position driving data collection.* As outlined in the resource titled Connected Intersections MAP Utility Assessment, vehicles equipped with highly accurate GPS receivers with RTCM correction drive each approach collecting data. These data are recorded and processed through the MAP Utility to provide a graphical view pass/fail report of the ability of OBUs to correctly determine the lane of travel. More details of this approach (including the pass/fail criteria and details of the process) are available in the Connected Intersections MAP Utility Assessment document prepared by CAMP.

<u>Guidance</u>:

For a <u>field survey to collect actual lat/lon/elevation data</u>, use your agency approach to determine the latitude, longitude, and elevation of the following:

- The point at which the center of lane edge lines for each ingress lane intersect with the upstream edge of the stop line.

- At the position of at least one additional location upstream in the ingress lane, measure the center of both edge lines.

- In situations where the ingress lane has a horizontal curve, measure additional locations (center of both edge lines).

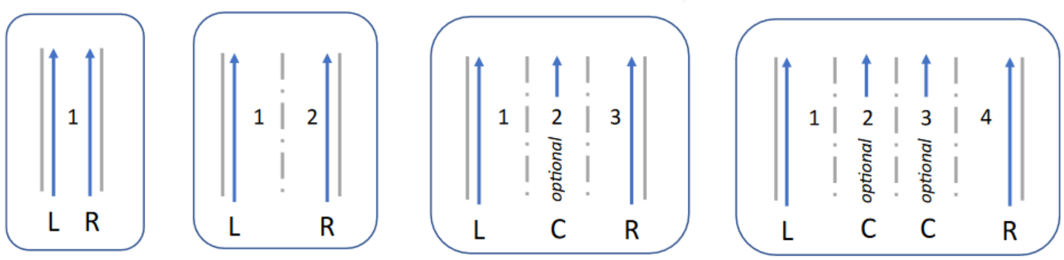
- Using the lane edge positions at the stop line, calculate the lane center at the stop line. Compare this value to the MAP message's first node for this ingress lane and adjust the value in the MAP message to reflect to measured position.

- Using the lane edge positions at the additional location upstream of the ingress lane, compute the lane center point and create a lane centerline using the lane center at the stop line and this additional lane center. Once a lane centerline is computed, the position of any MAP message centerline nodes can be compared to this center line and perpendicular distance to centerline calculated.

- In locations with a horizontal curve, measure and record the center of both edge lines for additional points within the curve.

For a <u>Vehicle position driving data collection</u>:

- Follow the data collection method described in the resource titled "CI MAP Utility Assessment Procedure" to collect data by driving each approach at least 16 times (and possibly more for multi-lane approaches). This is conducted with one set of eight driving runs positioned in the right portion of the lane (i.e., R) and a second set of eight driving runs positioned in the left portion of the lane (i.e., L). The assessment requires 7 of 8 runs for R and 7 of 8 runs for L to match the through lane for each approach. This is assessed using CAMP's bounding box analysis tools as OBU errors occur in certain situations that may be the result of proprietary algorithms. During the driving tests, the drivers should maintain position close to the left/right lane boundaries of the combined set of lanes (associated with the same signal group) without the tire touching the lane. This process is outlined in more detail in the CAMP CI MAP Utility Assessment Procedure. Figure 13 illustrates the required and optional drives for multiple lane configurations.



Source: Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure 5 (V2I-5) Consortium, 2022

Figure 13. Illustrative Sets of Driving Runs for Vehicle Position Driving Data Collection

- CAMP has conducted the drives for this data collection approach and estimated the time to be 2.5 - 3 hours for a single intersection. Another experience driving intersections to collect data suggests that conducting a driving run one time for each approach lane can be completed for eight intersections within one hour. The actual time to complete driving runs for data collection will depend upon distances to safe turn around points, distance between intersections, and whether additional optional runs will be conducted.

<u>Basis</u>:

- MAP message accuracy is critical. Both approaches represent valid approaches (tested in CV PFS sites).

2.6.2.9 Step 6 – Guidance #6.9: Make Changes to Correct Errors and Retest

Overview:

After completing the CI Requirements Validation document, each requirement will be assigned "Met", "Partially Met", or "Not Met". Each of these requirements are specifically identified in the *CTI 4501 v01.01 CI Implementation Guide* and therefore, each site should seek achieving "Met" for all requirements. **Error! Reference source not found.** identifies stakeholders who may potentially support troubleshooting efforts when requirements are either "Not Met" or "Partially Met."

Guidance:

- For any requirements "Not Met" or "Partially Met" that relate to SPaT message formatting or completeness, share the test results with the contractor or staff responsible for the ECLA and with the signal control vendor. It is possible that a firmware upgrade to the signal controller or ECLA will correct these issues.
- For any requirements "Not Met" or "Partially Met" that relate to SPaT message accuracy, share the results primarily with the signal controller manufacturer and with traffic signal staff responsible for configuration and operation of the signal controller. It is possible that settings, configurations, or firmware updates will correct the issues.
- For any requirements "Not Met" or "Partially Met" that relate to MAP message formatting, completeness, or accuracy, share the test results with the individual or group responsible for the MAP message creation and ask their assistance in updating the MAP message.
- For any requirements "Not Met" or "Partially Met" that relate to broadcast range, share the test results with the RSU manufacturer and with staff responsible for determining location and installing the RSU. Figure 14 below illustrates possible team members who may assist in troubleshooting errors.

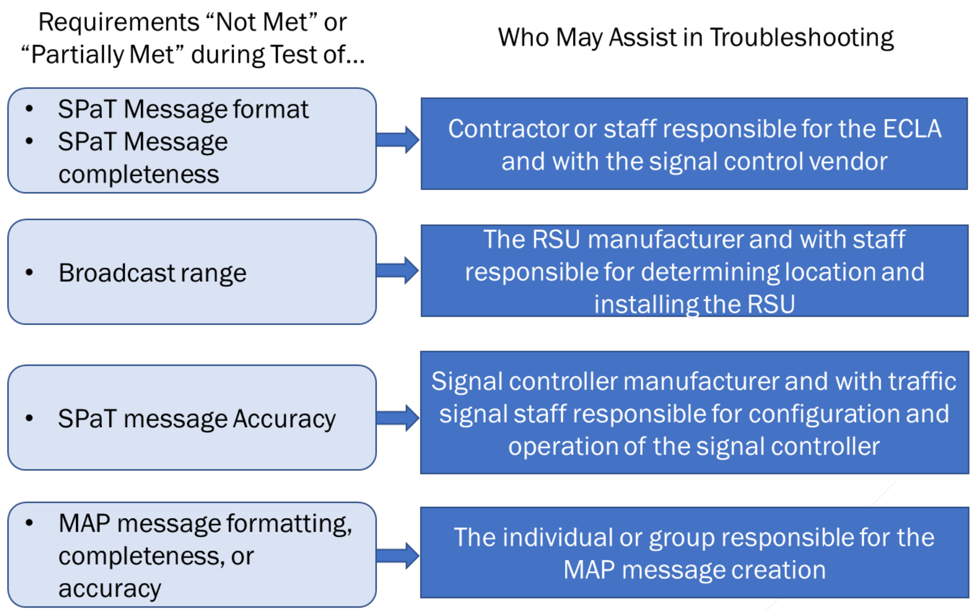


Figure 14. Possible Team Members Who May Support Troubleshooting Errors Identified During Testing

- As changes are performed, test the specific requirements to determine if requirements are "Met". Examples of situations that should merit repeating the process to validate an intersection include:
    - Installation of new firmware at the signal controller, ECLA, or RSU that are not tested in a bench test environment (i.e., if bench testing of the firmware change is successful, field validation is not required.
    - A change in the intersection geometry that has led to a significant change to the MAP messages (i.e., minor changes to the MAP message, such as speed limit changes may not require repeating the validation process).

Basis:

- Assigning issues to appropriate individuals or groups is the most direct approach to resolving errors.

2.6.3 Summary and Outcomes of Step 6

Upon completing Step 6, practitioners should have completed field validation activities to confirm that all requirements have been met and that the CI is operating as intended. Even though the CI meets all requirements, the broadcast messages will not be recognized by OEM production vehicles for use in in-vehicle safety applications like RLVW. In order for this to occur, Vehicle Verification will need to occur, as described in Step 7 so that the CI will be eligible to be provisioned with SCMS certificates that are trusted by OEM production vehicles.

2.7 STEP 7 – VEHICLE VERIFICATION

Step 7:
Vehicle Verification

The purpose of vehicle verification is to demonstrate that a CI is broadcasting complete, accurate, consistent SPaT, MAP, and RTCM messages and can be trusted by OEM production vehicles that are equipped to receive and use the CI broadcasts for the in-vehicle RLVW application. The exact steps, procedures, and options for conducting vehicle verification are still being determined (e.g., who to contact, who will conduct the testing, etc.). A group called the SCMS Manager will be responsible for issuing credentials that are trusted by OEMs to the IOOs for each fully verified intersection. For this to occur, SCMS Manager will be notified when vehicle verification is successfully completed and provide certificates with credentials that are trusted by OEM production vehicles.

2.7.1 Objective

The goal for Step 7 is to help practitioners to understand the concept of Vehicle Verification. Step 7 includes a series of steps IOOs are likely to execute based on what is currently known. Because this topic is still being developed through collaboration between IOOs, OEMs, and SCMS Manager, there are inherent gaps in the guidance until more information is made available.

2.7.2 Step 7 Guidance

CI deployers are encouraged to conduct vehicle verification as identified in Table 15 below during Step 7. CI deployers should adapt this guidance to local constraints, conditions, and the specific goals for the CI deployment.

! The topic described in Step 7 is currently being developed through collaboration between IOOs, OEMs, and SCMS Manager. This guidance is based on anticipated outcomes, and more experience with the established process will be needed to determine more definitive guidance.

Table 15. Step 7 – Vehicle Verification: Guidance List

Step 7 – Vehicle Verification	Guidance #7.1	Plan for Vehicle Verification
	Guidance #7.2	Conduct Vehicle Verification Drive Through Testing
	Guidance #7.3	Make Corrections to Any Identified Deficiencies
	Guidance #7.4	Report Fully Verified Connected Intersection

2.7.2.1 Step 7 – Guidance #7.1: Plan for Vehicle Verification

Overview:

In order to agencies to obtain security credentials that will be trusted by OEMs operating RLVW applications in production vehicles, vehicle verification will be performed following field validation. It is expected that the eventual procedure to initiate vehicle verification will involve the agency providing notification to their SCMS provider that field validation has been completed at the CI, all requirements have been met, and that the CI is ready for verification. The exact steps, procedures, and options for conducting vehicle verification are still being determined (e.g., who will conduct the testing, etc.). Additionally, since the agency will not have OEM trusted security credentials until verified, some process for preliminary credentials to support verification will be determined, both for field verification and bench testing.

While final details are not available, it is anticipated that the vehicle verification process will not be a situation where only one SCMS provider is able to verify CIs. Rather, all SCMS providers will have the opportunity to establish their verification process that meets the verification process established by the industry group working to establish this. Therefore, the SCMS certificate provider procured in earlier steps will likely be the recipient of the verification data and may be the "accepter" of the data. However, it is unknown who will be responsible for verification of the intersection. Options discussed in early discussions have included:

1) Self-certification by the IOO;
2) Certification by a third party; and
3) A certification body, such as OmniAir.

In order to conduct this phase of testing, IOOs are expected to perform some planning activities to prepare for vehicle verification.

Guidance:

- Complete bench testing and field validation, then make any necessary adjustments and validate that any issues have been corrected. The intent of vehicle verification is not to conduct any debugging of the system or to identify needed modifications. The intent is that IOOs have completed the validation process for their CI and IOOs trust that the intersection meets all requirements and is broadcasting complete, accurate, consistent messages.

- Additional details such as lead time and scheduling processes will be available once the verification process is established and are expected to vary by SCMS provider.

Basis:

- Evolving process, planning will be required but still are unknowns.

2.7.2.2 Step 7 – Guidance #7.2: Conduct Vehicle Verification Drive Through Testing

Overview:

The test cases and procedures for vehicle verification drive-thru testing are still evolving but will eventually be defined and documented. The role of the local agency is anticipated to be minor unless there is a self-certification process, but there are some possible actions that may be required (to be updated as more is known).

Also, it is not known if agencies will pay a fee for vehicle verification to be conducted and/or have the option to perform it locally vs. paying for another entity to conduct the vehicle verification.

Guidance:

- Provide support to vehicle verification drive-thru testing, as requested and outlined in the test procedures (not yet available). Depending upon the final defined test activities, the vehicle conducting the testing may request or require a trailing IOO vehicle (possibly with flashing lights) to support their driving maneuvers.
- Agency staff should be available to discuss test outcomes and, if feasible, potentially adjust CI configurations or equipment while testing is being conducted in order to correct identified errors.
- It is not known if vehicle verification will request additional support (e.g., triggering pedestrian calls or vehicle actuations) during the vehicle verification phase.

Basis:

- Evolving process but drive through testing anticipated.

2.7.2.3 Step 7 – Guidance #7.3: Make Corrections to Any Identified Deficiencies

Overview:

After vehicle verification testing is completed, any identified issues should be addressed and corrected. It is anticipated that the vehicle testing plans will describe a process for requesting re-testing, when needed.

Guidance:

- Follow recommendations from your contracted SCMS provider to make any adjustments needed to allow the CI to be fully verified.

Basis:

- SCMS provider will be responsible for accepting the verification.

2.7.2.4 Step 7 – Guidance #7.4: Report Fully Verified Connected Intersection

Overview:

After all phases of testing are completed and vehicle verification is considered successful, the CI will be considered fully operational and validated. The result of a fully verified CI will be that the agency receives SCMS certificates that are recognized by OEM production vehicles for use in in-vehicle applications like RLVW.

The process for reporting validated CIs is still under development but is generally envisioned to be that the verified status of intersections will be reported by the contracted SCMS provider for the intersection (perhaps in association with the local IOO) to SCMS Manager, which will then issue trusted SCMS certificates to the SCMS provider.

Additionally, SCMS Manager (or another designated group) may compile a nationally maintained list of CIs to inform OEMs and their vehicles about what CIs are verified.

Guidance:

- Follow procedures outlined by OEMs and/or SCMS Manager to report fully verified intersections.

Basis:

- Needed step in verification process.

2.7.3 Summary and Outcomes of Step 7

Upon completing Step 7, practitioners should have completed vehicle verification and have a fully operational CI. Most of the activities discussed in this Step are based on anticipated outcomes of ongoing discussions, and more information will be available as this processed is finalized and conducted at various locations to verify CIs.

2.8 STEP 8 – OPERATIONS AND MONITORING

Step 8:
Operations and Monitoring

The successful validation and verification of a CI indicates that it is operating in a way that meets or exceeds all requirements defined by the *CTI 4501 v01.01 CI Implementation Guide*. For purposes of this section, this operational state is referred to as "Normal Operations".

Given the nature of each CI operating as a self-contained system, a major part of normal operations is making sure that channels of communication and implemented business processes remain in place so that disruptions or changes at the intersection that cause broadcast information to be incorrect are detected and addressed as soon as possible. Normal operations at a CI typically include:

- *SPaT Operations.* Operating and maintaining the connection between the signal controller and the RSU to ensure content is continuously generated for broadcast to connected vehicles at the required frequency.
- *MAP Updates.* Ensuring that information in the MAP message continues to be accurate. This will require collaboration with agency construction and maintenance groups to understand when geometric changes or re-striping projects may require an update to the MAP message, and with the agency traffic signals group to understand when the assignment of signal groups changes. When changes occur, the MAP message will need to be updated, tested, verified, and uploaded to be broadcast by the RSU.
- *Position Correction Operations.* Operating the selected approach to generate location position correction messages (i.e., RTCM messages) continuously without interruption and to communicate them to the RSU to be broadcast.
- *Security Operations.* Operating security credentialling business practices to ensure credentials are being created, as needed and delivered to the RSU. Currently, this requires internet access beyond the agency firewall to access new certificates as needed.
- *RSU Message Broadcasts.* Ensuring that the RSU is attaching credentials and broadcasting the SPaT, MAP, and RTCM messages at the required frequency.
- *Message Monitoring.* Ensuring that a monitor is operating as intended to detect situations when the SPaT, MAP, and RTCM broadcasts are either not accurate or not broadcasting. Note that the detections of abnormal operations by the message monitoring system is described below.
- *Receiving Data Communications.* Receiving desired data that is collected at the CI and transmitted to the agency back office for reporting, performance measurement, analysis, and

archival purposes. This will be needed if BSMs are transmitted to the agency for analysis or archival, for example.

- *Routine Maintenance and Updates.* Making visits to the CI to repair or replace physical components, as needed and as depicted in Figure 15, as well as routine inspections according to asset management schedules. Other updates to software, for example, may be conducted remotely, as they are released and implemented by the agency.

- *Periodic Testing and Validation.* Conducting routine visits to the CI on a scheduled basis to confirm ongoing functionality and accuracy.

2.8.1 Objective

The goal for Step 8 is to help practitioners understand what is needed to operate and monitor a CI. This step leverages the IOO/OEM Forum "Consistent Procedures for Operations" document and refers to principles defined in the document. This step also defines "Normal Operations" and discusses identifying, responding, restoring from disruptions to Normal Operations.

Source: Federal Highway Administration

Figure 15. Routine Maintenance is Part of Normal CI Operations

2.8.2 Step 8 Guidance

Deployers are encouraged to operate and monitor CIs as identified in Table 16 below for Step 8. CI deployers should adapt this guidance to local constraints, conditions, and the specific goals for the CI deployment.

> **!** Step 8 Guidance is based on anticipated outcomes and requires additional experiences with the outlined processes to determine more definitive guidance.

Table 16. Step 8 – Operations and Monitoring: Guidance List

Step 8 – Operations and Monitoring		
	Guidance #8.1	Implement a Message Monitor System
	Guidance #8.2	Establish Business Processes for Proactively Identifying Disruptions
	Guidance #8.3	Establish Business Processes for Responding to Disruptions
	Guidance #8.4	Establish Business Processes for Restoring Operations After Updates or Disruptions
	Guidance #8.5	Incorporate Connected Intersections into Asset Management Processes
	Guidance #8.6	Engage with Pertinent Groups for Latest Updates

2.8.2.1 Step 8 – Guidance #8.1: Implement a Message Monitor System

Overview:

Once the CI validation and verification process is complete, the intersection is trusted to be delivering complete, accurate SPaT, MAP, and RTCM messages. However, the certainty that these messages remain complete and accurate will diminish over time, introducing the question of "How often should CIs be revalidated". There is no way of determining how frequent is "frequent enough" to revalidate intersections. For this reason, an automated and continuously operating approach to detecting malfunctions, interruptions of service, or other anomalies that jeopardize successful operations of the intersection is needed and envisioned to maintain continuous trust in CIs.

At the time this guidance is being created, the CV PFS has an active project to research and develop a Connected Intersection Message Monitoring System (CIMMS). Prototype development and testing is expected to occur as part of this process. It is recognized that CIMMS may only provide a partial solution, however it is expected to evolve as new needs are identified and new mechanisms are developed for monitoring. Additional message malfunctioning detection approaches may also be developed.

Guidance:

- Deployers of CIs are referred to the CV PFS CIMMS project. The project is following a systems engineering approach to design the system. Design will be followed by the creation of a prototype system to be tested in two CV PFS member sites during 2023. If successful, the outcome of the CIMMS project will be a message monitoring system that can be used by IOOs to monitor CIs.
- Deployers are encouraged to monitor the activities of the CV PFS for any additional activities to develop additional detection approaches beyond the CIMMS project.

Basis:

- The *Connected Intersections – Consistent Procedures for Operations* resource developed by the CAT Coalition IOO/OEM SPaT/RLVW Working Group contains Principle #3: Anomalies Must Self-Report to Ensure Accurate Messages. Specifically, self-reporting of anomalies by automated processes or system detection is a preferred option.

2.8.2.2 Step 8 – Guidance #8.2: Establish Business Processes for Proactively Identifying Disruptions

Overview:

Successful implementations of message monitor systems will detect discrepancies between SPaT and MAP messages and the current situation and allow the operating agency to act to either correct the situation or to pause the broadcasts until they can be corrected. However, some of the disruptions that would be identified by a message monitoring system can be proactively anticipated and avoided. For example:

- *Temporary maintenance or construction.* A work zone at or near the CI may close or reposition lanes, making the MAP message not an accurate representation of the ingress and egress lanes into the intersection. If temporary, the original MAP message may only temporarily be inaccurate.

- *Any geometry changes at the intersection*, such as the addition of a new turn lane or realignment of existing lanes. In these situations, the geometric change is typically known and planned well in advance of the change. However, the group responsible for planning and implementing the change may not be the group responsible for operating the CI and this may result in a disconnect of communication about the planned change.

- *Signal Group assignment changes*. While changes to signal timing plans (e.g., implementing new timing plans with changes to the duration of interval periods) will not require changes to the MAP message, a change to the signal groups would require a MAP message change. This is because each MAP message connection is assigned to a signal group, therefore creating the link between MAP messages, and SPaT messages. Therefore, changes to a signal group in the signal controller will require reevaluation of the MAP message and most likely an update.

Guidance:

- Establish and maintain relationships with key groups and create business processes for sharing information to understand when changes or disruptions may occur at the CI. These processes may evolve as more CIs come online, based on the availability and resources of various groups within an IOO to support this function. Note that one challenge for these groups may be understanding what signalized intersections are connected, and relatively limited instances that disruptions would cause an impact at a CI.
    - *Signals Group*. Before new signal timing changes occur (which might impact signal groups defined in the MAP message), establish a process for signals staff to notify appropriate staff who manage the CI of the changes and date/time the changes are planned to occur.

- *Construction and Maintenance Groups.* Operations groups responsible for CI operations should monitor planned construction and maintenance activities to identify if geometric changes are occurring to any of the CIs (that might impact the MAP message).

- *TMC Operators*. In the event of an incident or maintenance activities (including non-agency disruptions, such as utility work) at the CI location, TMC operators may be able to quickly identify the disruption and notify appropriate staff. While TMC operators may not be available to fully support this task as more CIs come online, they may provide support in the near-term.

Basis:

- The *Connected Intersections – Consistent Procedures for Operations* resource developed by the CAT Coalition IOO/OEM SPaT/RLVW Working Group with input from OEMs included:

  - Principle #1: No Broadcasts of Incorrect Messages. A broadcast message containing incorrect information has the risk of doing greater harm than if no message were broadcast at all. Any broadcast message should always contain correct information.

2.8.2.3 Step 8 – Guidance #8.3: Establish Business Processes for Responding to Disruptions

Overview:

OEM in-vehicle applications will require trust that IOOs respond to disruptions and return CIs to normal operations as soon as possible. At the time this guidance was created, it is likely not practical for an IOO to immediately respond to all types of outages that may impact the quality of CI broadcasts, nor does the number of production vehicles operating in-vehicle applications justify prioritization of resources to such a response. However, in the coming years:

- More intersections are likely to become connected, with increasing numbers of products to support easier more efficient management of the broadcasts.

- More vehicles are likely to be equipped with in-vehicle applications.

- The role of in-vehicle applications is likely to change, possibly beyond supplemental warning systems to supporting partial or automated driving functions, increasing the reliance on the data broadcast by the infrastructure.

- The operations that IOOs perform will evolve with potentially an increased emphasis on maintaining the operational status of infrastructure broadcast.

The tactics that IOOs implement may evolve as these and other changes occur.

Note: The industry is only beginning to initiate discussions involving these topics. Sustained collaboration is needed to understand what is possible from current technologies and capabilities, what is possible as supporting technologies evolve, and the penetration rate of connected vehicles and reliance upon the data.

Guidance:

- Each agency should develop business processes that outline their approach to responding to disruptions. This may benefit from collaboration with other IOOs through groups such as the CV PFS. The following principles were defined by the collaboration of the IOO/OEM Forum of the CAT Coalition:

    - Absent messages are better than incorrect messages. Temporary periods where broadcasts of messages are absent are acceptable. (Note that this refers to "absent messages" over a period of time when a disruption like planned maintenance activities is occurring and does not allow for exceptions to message broadcast frequency requirements during normal operations.)

    - Messages that contain information that do not match physical conditions and traffic control in the field should no longer be broadcast or should be identified as "not valid".

    - In situations where the current lane configuration no longer matches the MAP message (e.g., during a temporary lane closure), the MAP message should not be broadcast. An exception would be if a supplemental warning message of "No valid MAP message available" is broadcast using a standard data exchange protocol, such as a TIM or Road Safety Message (RSM).

    - The "Safe State" to support in-vehicle applications is to stop broadcasting incorrect data.

- Possible business processes that may be chosen by an agency for various types of disruptions, include:

    - *Pause Broadcasts*. Implement a temporary stop/pause in broadcasting the messages. In situations where a physical activity impacts the intersection, the RSU broadcast may be paused while either the MAP or SPaT messages are not valid.

    - *Supplemental warning*. It may be more efficient to continue to broadcast SPaT/MAP messages while adding an indication in either the SAE J2735 message or the security WSA message to indicate the messages are not valid.

    - *Broadcast RSMs*. RSMs describing the maintenance or construction work zone event could be broadcast to help indicate to passing vehicles that the intersection operations may be disrupted.

    - *On-site Responder Broadcasts*. Alerts could be broadcasts by vehicles (e.g., law enforcement or first responder vehicles) at the intersection (e.g., stationary location, flashing beacons activated) that would help indicate to passing vehicles that intersection operations may be disrupted.

- *Take no action*. Wait for the temporary disruption to end. In situations where a lane is closed temporarily, the lane may reopen shortly after, and no action may have been performed in response to the outage. This is not the preferred approach, nor does it accomplish the principle that an absent message is better than an incorrect one, but the reality is that this is an option that may be executed.

Basis:

- The *Connected Intersections – Consistent Procedures for Operations* resource developed by the CAT Coalition IOO/OEM SPaT/RLVW Working Group with input from OEMs, contains Principle #1: No Broadcasts of Incorrect Messages. A broadcast message containing incorrect information has the risk of doing greater harm than if no message were broadcast at all. Any broadcast message should always contain correct information.

2.8.2.4 Step 8 – Guidance #8.4: Establish Business Processes for Restoring Operations After Updates or Disruptions

Overview:

Restoring operations after an update or disruption entails either:

- Restarting the broadcast of previous messages that remain valid.
- Correcting an issue with the SPaT or RTCM message generation.
- Creating new MAP messages to update information (e.g., if re-striping or reconstruction has changed the physical characteristics of the intersection and a new MAP message is required).

Some testing will likely be required to restore CI operations following any disruption or updates that are made. This testing is expected to be only a subset of the full test procedures that are used for initial implementation. Additionally, no details have been defined on the process for repeating vehicle verification following outages.

Guidance:

- The restoration of CI operations after a disruption should follow a gradual, methodical approach that ensures consistency and accuracy of broadcast messages (i.e., instead of a faster approach that results in errors or incorrect messages and requires additional disruptions to CI operations to correct those errors).

Basis:

- The *Connected Intersections – Consistent Procedures for Operations* resource developed by the CAT Coalition IOO/OEM SPaT/RLVW Working Group with OEM feedback contains Principle #2: Restore Correct Broadcasts Progressively as Soon as Practical. Functionality of the CI should be restored in a progressive, gradual, reliable approach that results in messages containing correct information being broadcast as soon as is practical. Rather than hasty restoration of broadcasts that may be valid for a period of time and then not valid again, a gradual restoration process that minimizes the transitions from valid to not valid is preferred when restoring functionality once intersection operations have returned to a normal, operational state.

2.8.2.5 Step 8 – Guidance #8.5: Incorporate Connected Intersections into Asset Management Processes

Overview:

Agencies maintain extensive asset management systems to support routine maintenance activities and funding for signal assets. While the intersection will likely be included in these asset management systems, CIs include additional technology components and will have increased maintenance and/or testing needs over a traditional signalized intersection. For instance, a CI is likely to require software and firmware updates that would not be needed at a traditional signalized intersection. Also, the CI may require periodic testing of functionality. At the same time, a CI may have different lifecycle expectations given the evolving nature of functional requirements, availability of new technologies, and limited experience regarding maintenance needs for these relatively new technologies.

> *Example*: The Florida DOT compensates local agencies to maintain CI devices but is still learning the anticipated funding required on an annual basis for these devices; initially, more funding was allocated in case crews needed to be dispatched to repair CI devices, but this has not occurred as frequently as anticipated.

Guidance:

- Practitioners are encouraged to collaborate on integrating CI technologies with existing agency traffic signal (or other) asset management systems to facilitate and track planned and special maintenance activities and be included in funding considerations.
- Ongoing testing and verification (in compliance with any recurring verification required by SCMS Manager to maintain security credentials) should be planned and documented as part of the asset management process.

Basis:

- Examples have been documented where MAP messages have not been updated after geometric changes at the intersection. Incorporation into an asset management process will help to ensure appropriate updates and maintenance are performed.

2.8.2.6 Step 8 – Guidance #8.6: Engage with Pertinent Groups for Latest Updates

Overview:

CIs will continue to evolve. Until CIs reach a stable state of maturity, the applicable standards, technology, applications, and software may frequently change and require updates. In order to stay abreast of the latest developments, practitioners are encouraged to engage with pertinent national forums and organizations in order to track what updates may be needed at agency CIs to maintain full functionality and operability with connected vehicles.

These organizations and groups may include:

- ITE/USDOT CI Working Groups.
- Connected Vehicle Pooled Fund Study.
- AASHTO CTSO CAT WG.
- SAE.

Guidance:

- Practitioners are encouraged to participate in national forums and organizations to be aware of new requirements, technologies, or updates needed to maintain fully operational CIs.

Basis:

- Evolving industry standards, resources, and lessons learned.

2.8.3 Summary and Outcomes of Step 8

Upon completing Step 8, practitioners should understand what is necessary to support normal CI operations, including business processes and monitoring to identify and respond to disruptions, as well as activities needed to maintain and upgrade CI components. The number of fully verified and operational CIs is currently limited, but more information will be available as more CIs are deployed in the future.

3. Conclusion and Next Steps

3.1 USE OF DOCUMENT

Readers are encouraged to use this document as they prepare and deploy CIs. Readers should also have several other key resources available for easy reference, as they are critical to deploying CIs and this document does not copy relevant information from applicable standards and resources. Instead, this guidance references these documents and provides additional explanations as they are needed to help interpret and apply the information in these documents. Key resources include:

- *SAE J2735 V2X Communications Message Set Dictionary*.
- *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide*.
- *Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard*.
- *Connected Vehicle Pooled Fund Study (CV PFS) MAP Guidance*.
- *National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) 1202 v03A*.

Additionally, practitioners should regularly check the online source for these documents to ensure the latest available versions of information are being referenced.

As with the standards, CI technologies and deployment processes are expected to evolve over time. New strategies, approaches, and industry collaboration may result in modifications to CI requirements, as well as associated expectations for security, monitoring, and testing. These changes, as well as increased practitioner familiarity with CIs, are likely to streamline deployment of CIs. Ultimately, this Guidance document is an early attempt to summarize an approach for deploying CIs to support unfamiliar practitioners and is not expected to be a document that will be needed in perpetuity. Instead, while updated versions of this document may be released, increased practitioner familiarity combined with increased deployment and more user-friendly and off-the-shelf technologies and tools are expected to reduce the need for CI deployment guidance over time.

Finally, Finally, some guidance items in this document are described as being in development and not final. In addition to other possible updates to the guidance, these will be clarified if/when possible, based on the direction and approval of the CV PFS.

3.2 DOCUMENT FEEDBACK

It is understood that the content of this Guidance document is either new or has only been minimally used. Additionally, some of the specific Guidance contains information that is either incomplete or based on anticipated outcomes, while additional standardization, technology development to meet relatively new CI requirements, and deployment experiences are still needed to validate the approach described and provide additional details

As such, the Connected Vehicle Pooled Fund Study is soliciting input from any users of this Guidance to improve upon this document in future versions. Specifically, any reactions or feedback to the content in this document is encouraged, including identified errors, points to clarify, alternate approaches, and IOO deployment experiences. This feedback should be sent to CV PFS members or the CV PFS Program Coordinator, Mallory Artusio, at martusio@virginia.edu.

3.3 POTENTIAL FOR FUTURE REVISIONS

Because the deployment of CIs is a relatively new, evolving, and dynamic topic, more resources, technologies, and services are evolving or becoming available, and more IOOs are gaining deployment experiences. As such, there will likely be a need to update this Guidance document in the future to reflect these changes. Updates may include:

- Inclusion of new resources and standards developed by ITE, SAE, NTCIP, USDOT, the CV PFS, or other entities.
- Inclusion of new processes developed for vehicle verification, operations, and monitoring.
- Changes or edits to the guidance to provide clarification or updates based on received feedback, new developments in the industry, and deployment experiences.
- Additional examples based on successful IOO deployments.

Readers are encouraged to check for any updates to this Guidance on the CV PFS website.

Appendix A. References

Key Standards and Guidance Resources for Connected Intersections

- *SAE J2735 V2X Communications Message Set Dictionary*. Specifies a message set, and its data frames and data elements, for use by applications that use V2X communications systems.
- *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide*. Standardizes the key capabilities and interfaces for a CI, and addresses the ambiguities and gaps identified by early deployers and provide enough guidance to generate messages and develop applications for signalized intersections that are truly interoperable across the United States, especially for automated transportation systems.
- *Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard*. A non-proprietary, communications-agnostic, industry consensus standard for RSUs, a transportation infrastructure communications device that is a key part of a Cooperative Intelligent Transportation Systems (C-ITS) transportation environment.
- *Connected Vehicle Pooled Fund Study MAP Guidance*. Provides guidance on the creation of MAP messages to be used with corresponding SPaT messages for non-automated intersection approach and violation applications.
- *National Transportation Communications for Intelligent Transportation Systems Protocol (NTCIP) 1202 v03A*. Standardizes data elements for use with Actuated Signal Controller Units, such that a management station may interface with a field device to control and monitor traffic signal controllers and associated detectors.

Additional Resources to Support Connected Intersections Bench Testing and Field Validation

- *Connected Vehicle Pooled Fund Study CI Test Plan*. Comprehensive test plan to test for basic RLVW functionality. Test activities exclude a limited set of requirements not related to basic RLVW and may not fully test CIs for all OEM applications. This document describes CI test activities completed for Ohio, Georgia, and Utah.
- *Connected Vehicle Pooled Fund Study CI Detailed Testing Log*. Describes the validation methodology recommended to test each requirement, together with designated space to enter results and explanation as testing is conducted.
- *Connected Vehicle Pooled Fund Study Utah Data Collection Plan*. A brief, informal document used to describe data collection activities to ensure the staff collecting data in the field gather all the needed data and have pre-defined routes of travel and static data collection locations.

- *Connected Vehicle Pooled Fund Study CI Utah DOT Test Results Report*. Comprehensive report describing the tests performed and results, including areas for improvement for requirements that were either partially met or not met.

- *CAMP LLC CI MAP Utility Assessment Supporting Red Light Violation Warning, Version 0.90 (August 16, 2022)*. Describes an available on-line utility that can be used to test MAP message format and MAP accuracy if accompanied by drive data collected by and OBU.

- *CAMP LLC CI SPaT Accuracy Assessment, Version 0.6 (July 26, 2022)*. Describes the data collection and analysis for two key items critical to success of RLVW applications: Yellow phase duration accuracy and SPaT transmission periodicity.

- *CAMP LLC SPaT/MAP Utility, Version 1*. On-line tool that allows the upload of JSON files and processes them to analyze SPaT and MAP messages. Analyses include SPaT message format, MAP message format, and SPaT broadcast periodicity. Note that additional details about the use of this tool are included in *CTI 4502 v01*, listed below.

- *Connected Transportation Interoperability (CTI) 4502 v01 Connected Intersections Validation Report*. Summarizes findings from the 2021 ITE CI project validation phase.

Other Resources for Connected Intersections

- *Cooperative Automated Transportation Coalition IOO/OEM SPaT RLVW Working Group: Connected Intersections – Consistent Procedures for Operations*.

Appendix B. Documentation from Guidance Steps

This appendix compiles documentation presented in Step 1, Step 2, and Step 3 that is recommended for practitioners to complete to support the deployment of a CI. The documentation is summarized in Table 17.

Table 17. Documentation Developed in Step 1 and Step 2 for Use in Later Steps

Documentation	Developed as Part of...	For Use in...
Summary of Signal Control Equipment	Guidance #1.1	Guidance #3.1
Intersection Movement Controls Questionnaire	Guidance #1.2	Guidance #3.1
Completed Network Readiness Checklist	Guidance #1.3	Guidance #3.1 and Guidance #3.2
Completed MAP Server Questionnaire	Guidance #1.4	Guidance #3.2
Completed ATMS Questionnaire	Guidance #1.5	Guidance #2.8, Guidance #3.1, and Guidance #3.2
NRTM for RTCM *(see CTI 4501 v01.01)*	Guidance #1.6	Guidance #3.5
Completed CORS/RTCM Questionnaire	Guidance #1.6	Guidance #3.5
Physical Infrastructure Makeup Questionnaire	Guidance #1.7	Guidance #3.1
Completed Testing & Verification Capabilities Checklist	Guidance #1.8	Guidance #3.1
Completed Signal Controller NRTM *(see CTI 4501 v01.01)*	Guidance #2.1	Guidance #3.1 (and Guidance #2.2)
List of Needs for ECLA	Guidance #2.2	Guidance #3.2
Desired RSU Certifications and Additional Requirements	Guidance #2.3	Guidance #3.3
Downloaded RSU NRTM (see *CTI 4001 v01*)	Guidance #2.3	Guidance #3.3 (and Guidance #2.4)
Completed Owned RSU NRTM (see *CTI 4001 v01*)	Guidance #2.4	Guidance #3.3
Notes on Other RSU Options	Guidance #2.5	Guidance #3.3
Notes on Options for Procurement	Guidance #2.7	Guidance #3.3
Key High-Level Design Decisions	Guidance #2.9	Guidance #3.1, Guidance #3.2, Guidance #3.3, Guidance #3.5, and Guidance #3.6
Checklist of Facilities and Equipment Needed for Testing	Guidance #3.7	Guidance #5.2, Guidance #5.3, and Guidance #6.3

Documentation 1.1 Summary of Signal Control Equipment

Intersection ID:______ Name of cross streets:________________________ Date:__________

1. Time source for the controller is _______________
2. Is the signal controller time reporting local time? Coordinated Universal Time (UTC) time? Other? ____________________
3. Are there any additional servers or devices at the intersection? ____
   If so, what are the time sources of these servers? _______________
4. Please indicate if there is additional space in the controller cabinet and, if so, approximate space for additional items ____
5. Please describe available power supplies and access at the intersection ____
6. Are there any existing servers in the cabinet that may be used to locate software to support the connected intersection? ______________
7. Please describe the signal controller brand, model, and any capabilities described in the specifications (attach a PDF of specifications if possible) _________________________________
8. Please identify the representative name and contact information that can be contacted for additional information on the intersection____

Save this completed documentation for use in procurement in Step 3.

Documentation 1.2 Intersection Movement Controls Questionnaire

Intersection ID:______ Name of cross streets:__________________________ Date:__________

1. Please indicate which movement controls are included in signal timing plans for this intersection:
   - ❑ Protected/Permissive turns
   - ❑ Protected turns
   - ❑ None of the above
2. Please indicate if any of the following exist at this intersection:
   - ❑ Lanes that reverse direction by time of day
   - ❑ Allowed movements (e.g., left-turn, right turn) that are not allowed at times of the day
   - ❑ Vehicle lane restrictions that vary by time of day (e.g., no trucks allowed a portion of the time, parking not allowed during limited time periods)
   - ❑ None of the above
3. Describe all possible phase transitions involving flashing arrows
   - ❑ FYA => YA => RA => GA
   - ❑ FYA => GA

Save this completed documentation for use in procurement in Step 3.

Documentation 1.3 Required Network Functionality Readiness

Intersection ID:______ Name of cross streets:________________________________

Date:__________

1. Are either of the following available: a) Internet connectivity to the intersection, or b) Indirect Internet access via an internal (i.e., IOO) network that remotely connects to allowed Internet uniform resource locators (URLs)?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown
2. Is a secure local network connection available at the intersection as an option for connecting an RSU, ECLA, signal controller, and additional servers, as needed?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown
3. Is a firewall available that protects the local network?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown
4. Is an Internal Network available at the intersection to support a secure transport protocol with mutual authentication (i.e., Transport Layer Security (TLS) or Datagram Transport Layer Security (DTLS) with client certificates)?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown
5. Is remote connectivity to the local network available for authorized contractors, vendors, and/or TMS data communications?
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

Save this completed documentation for use in procurement in Step 3.

Documentation 1.4 MAP Message Storage Options Questionnaire

Intersection ID:______ Name of cross streets:_________________________ Date:__________

1. Is your agency approach to locate the MAP Message at the RSU (and apply SCMS signatures at the RSU)?
   - ❑ Yes
   - ❑ No, or no current policy

   Note: If Yes, you do not need to complete the remainder of the questionnaire.

2. Does your agency have a central MAP server where you will locate the MAP message for this intersection?
   - ❑ Yes
   - ❑ No

   Note: If Yes, you do not need to complete the remainder of the questionnaire.

3. Are there any other preferences for locating the MAP server:
   - ❑ Locate MAP server on the ECLA
   - ❑ Deploy a separate server to house the MAP message
   - ❑ We have no preference

Save this completed documentation for use in procurement in Step 3.

Documentation 1.5 ATMS Questionnaire

Intersection ID:______ Name of cross streets:___________________________ Date:__________

1. Is there an ATMS system in-place with established communications to this intersection?
   - ❑ Yes
   - ❑ No

   Note: If No, please describe any capabilities to perform remote control or send/receive files with the signal controller or other servers in the signal cabinet:____

2. If Question #1 is yes, describe the ATMS vendor/support
   - ❑ Developed and supported in house
   - ❑ Purchased and supported by a vendor. Vendor is _________________________

3. If Question #1 is yes, can the ATMS support the following activities?
   - ❑ Communicating MAP messages to the RSU or MAP Server
   - ❑ Allowing software or firmware upgrades to the RSU
   - ❑ Communication of RTCM messages
   - ❑ Remote management functions and control of power to the RSU
   - ❑ Programming updated SPaT information to the signal controller (e.g., revocable lanes)

4. When you contacted the ATMS vendor/support, did they indicate whether their system has been integrated with any RSUs:
   - ❑ Yes, successfully integrated with the following RSU brands
   - ❑ Yes, and noted compatibility issues summarized as ______________(include RSU vendor with any issues)
   - ❑ They have not had experience integrating with RSUs

Save this completed documentation for use in procurement in Step 3.

Documentation 1.6a NRTM for RTCM can be found in *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide*. Completed Signal Controller NRTM

Documentation 1.6b CORS/RTCM Questionnaire

Intersection ID:______ Name of cross streets:__________________________ Date:__________

1. Are you aware of a statewide or local CORS network/system that offers position correction data? (note: CORS operations may be partnerships between state DOTs and local counties, cities and private companies. We recommend checking with your surveying or land management groups to explore the availability of CORS).
   - ❑ Yes
   - ❑ No, we do not have access to a public operated CORS
   - ❑ Unknown

   Note: If Yes, you do not need to complete the remainder of the questionnaire.

2. If Question 1 is “yes”, does the coverage of your CORS include the location of the intersection? (note: you may find this information from either locations of base stations supporting CORS data (base stations should be within 25 miles of the intersection, or from CORS coverage maps indicating geographic area covered by the network of stations).
   - ❑ Yes
   - ❑ No

   Note: if Question 2 is No, you do not need to complete the remainder of the questionnaire.

3. Research if there are any connected intersections (operated by your agency or partner agencies (e.g., local cities or counties) that are within 25 miles of this intersection. Share the *CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide* with the CORS support team, requesting them to review the RTCM requirements in the NRTM table (2.4.3.1.1 “Uniform” section) – Note: the *CTI 4501 v01.01 Connected Intersections (CI) Implementation Guide* references the SAE J2735_202007 standard, therefore this will need to be shared with the CORS support team.
   - ❑ Our CORS support team has reviewed the standards and determined CORS is able to supply the RTCM formatted messages
   - ❑ Our CORS support team has reviewed the standards and determined CORS is <u>NOT</u> able to supply the RTCM formatted messages
   - ❑ We are still researching

Save this completed documentation for use in decisions about RTCM in Step 3.

Documentation 1.7 Physical Infrastructure Makeup Questionnaire

Intersection ID:______ Name of cross streets:_________________________ Date:__________

1. Have you identified a mounting location for the RSU?
   - ❑ Yes. Please describe the location (e.g., southwest corner mast arm) insert pictures if possible
   - ❑ No

2. Have you assessed local connections from the proposed RSU site to the signal controller?
   - ❑ Yes, a local power over ethernet cable connection can be established between the signal controller and RSU
   - ❑ No, unknown

3. Have you completed a visual line of sight survey for this location?
   - ❑ Yes, no obstructions were noted
   - ❑ Yes, the following obstructions may pose issues to the RSU ________________________

Save this completed questionnaire as it may be used in procurement in later steps.

Documentation 1.8 Testing and Verification Capabilities Checklist

Intersection ID:______ Name of cross streets:_________________________ Date:__________

1. Is yellow phase end time data captured by the signal controller (or other data collection methods) available to support yellow phase interval duration analysis? (The onset of the yellow phase will be included in the SPaT message and therefore must represent an accurate time for when the yellow phase will end; it is not possible to observe this in the field.)
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

2. Can an output of signal controller phase onsets be logged and made available to compare with logged OBU data captures during testing and validation? (The time that SPaT messages are received by OBUs will be compared to the actual time of interval onset for the yellow and red phases. A test procedure is defined for conducting this using video capture of signal head change compared to OBU display. However, this log is necessary if the site wishes to conduct an additional, post analysis.)
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

3. Are all systems set to UTC time and drift minimized, in order to support testing at later stages? (The standards and supporting data exchanges for SPaT information use time "ticks" or countdowns or remaining seconds until interval changes. This addresses challenges of synchronicity issues between signal controllers, RSUs, and OBUs. However, to test and validate the time differences between interval changes, it is important to have time clocks synchronized, otherwise post testing analysis of the data is not possible.)
   - ❑ Yes
   - ❑ No
   - ❑ Unknown

Save this completed documentation for use in procurement in Step 3.

Documentation 2.1 Completed Signal Controller NRTM can be found in *Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide*.

Documentation 2.2 List of Needs for ECLA

Intersection ID:______ Name of cross streets:__________________________ Date:___________

Functions Beyond SPaT/MAP/RTCM Message Broadcasts:

1. Do you plan to broadcast messages to support other applications at this intersection beyond SPaT messages?
   - ❑ Yes, we are planning to broadcast TIM or RSM messages for reduced speed warning
   - ❑ Yes, we are planning to broadcast TIM or RSM for curve warning
   - ❑ Yes, we are planning to broadcast TIM or RSM for spot weather warning
   - ❑ Yes, we are planning to broadcast TIM, RSM, or Work Zone Data Exchange (WZDx) for work zone information.
   - ❑ Yes, we are planning to broadcast one or more additional “other” messages that may require ECLA support.
   - ❑ No
2. Do you plan to support signal priority or preemption using the CI functionality
   - ❑ Yes, we plan to use this RSU to receive priority/preemption requests and will require functionality to process requests and generate/broadcast priority reply messages
   - ❑ No, either we are not planning signal priority/preemption, or it is already supported by existing systems and will not use the CI
3. Are you planning to receive and process BSMs from vehicles and wish to process and incorporate the data into your operations?
   - ❑ Yes
   - ❑ No

If you answered “Yes” to any of the above questions, attach additional information about your planned deployments (e.g., any preliminary project summaries or concept definitions) as they will be helpful when procuring support for the ECLA.

SPAT NRTM Related Needs for the ECLA:

During Step 2.1, you interacted with your signal control manufacturer and received a response to the NRTM which likely identified requirements they may address through product upgrades and requirements they cannot address (and recommend for the ECLA). Create a subset matrix of those requirements that you would like to receive bids/estimates on from ECLA vendors or support contractors. This may be all the requirements marked as “Meets w/upgrade” or marked “ECLA” or you may have an understanding of what requirements you will address by working with your signal control manufacturer.

Assemble your answers to Questions 1-3 (including any attached descriptions or scoping deliverables) and the NTRM identifying those requirements you believe may be addressed by the ECLA and consider this collection of information – *Documentation 2.2 List of Needs for ECLA*.

Documentation 2.3a Desired RSU Certifications and Additional Requirements

Intersection ID:______ Name of cross streets:_________________________ Date:__________

1. ***Certifications.*** The following certifications have been identified as those that should be considered when assembling RSU specifications:
   - ❑ Certified RSU product category on the OmniAir website

2. ***Additional Requirements***
   - ❑ ***MAP Availability.*** The SAE J2735 SPaT Message include a status bit for "No MAP Available", that must either be indicated as the value 0 when a valid MAP message is available or as a 1 when no MAP is available. Check this box and note this functionality if you require the RSU to append the SPaT Data to indicate whether a valid MAP message is available.

3. Please list additional requirements, functions, or capabilities of the RSU beyond what is in the *CTI 4001 v01 RSU Standard* or those listed above (e.g., those you have learned from interactions with other agencies deploying connected intersections, feedback from CV PFS members, etc.).
   - ❑ ____________________
   - ❑ ____________________

Save this documentation as it may be used to support the procurement of new RSU devices in later steps.

Documentation 2.3b Downloaded RSU NRTM can be found in *Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard*.

Documentation 2.4 Completed Owned RSU NRTM can be found in *Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard*.

Documentation 2.5 Notes on Other RSU Options

RSU Make/Model:____________________

Using the RSU fact sheet/product sheet or specification, note the following information:

1. Is there any statement about meeting the requirements defined in the *CTI 4001 v01 RSU Standard*?
   - ❑ Yes
   - ❑ No

2. Note if any of the following mandatory features are identified for the RSU (these will be needed for your connected intersection)?
   - ❑ PCAP logging
   - ❑ Support for SAE J2735 SPaT, MAP, RTCM messages.
   - ❑ Security certificates
   - ❑ Hardware security module
   - ❑ Local Network Interface security
   - ❑ <Others>

3. Note if any of the following optional features are identified for the RSU (these may be needed based on local preferences or plans for the intersection)?
   - ❑ Support for TIM or BSM messages
   - ❑ Position correction/RTCM message generation
   - ❑ LTE/Cellular connectivity
   - ❑ <Others>

Documentation 2.7 Notes on Options for Procurement consists of any notes taken to document considerations in response to Guidance #2.7.

Documentation 2.9 Key High-Level Design Decisions

1. Signal Controller Output will be formatted according to: ________________________________
   (Options: TSCBM, SAE J2735, NTCIP 1202v03A, other)

2. There (will / will not) be an ECLA.

3. If an ECLA is planned, the role(s) will be: ________________________________

   ____
   (Options include: address requirements not met by signal controller like real-time message conversion or provision of supplemental data, storing MAP messages, testing / troubleshooting, receive and process BSMs process signal priority requests to adjust signal timing as part of network signal management system, other functions beyond message broadcast)

4. The RTCM source will be: ________________________________
   (Options include: state or local CORS network/system, commercially-available CORS data with subscription, deploying RTK base stations near the CI)

5. The communication mechanism for the RTCM information to reach the RSU will be:

   ____

6. The SCMS/security back-end location will be: ________________________________

7. The communication mechanism for the SCMS / security back-end to the RSU will be:

   ____

8. The RSU location will be: ________________________________

9. The communication capabilities between the RSU and ECLA (if applicable) will be:

   ____

10. The MAP message will be stored at: ________________________________
    (Options: the RSU, the ECLA, or the TMS)

11. The communications approach to upload new MAP messages to the storage location will be:

    ____
    (Options include: physical visit to device to load file, remote access to load file)

12. The communication mechanism for the MAP message to reach to RSU will be:

    ____

13. If applicable, the location of the ECLA will be: ________________________________

14. The approach to remotely terminating power and restoring power to the RSU will be:

    ____

Documentation 3.7 Checklist of Facilities and Equipment Needed for Testing

Typical facilities for conducting off-line testing (see CI Test Plan Section 6.6.1):

- ❑ Workbench space
- ❑ Surge Protection power strips
- ❑ A Conference Room, with whiteboard and/or flipcharts, etc.
- ❑ Internet access

Typical equipment for conducting off-line testing (see CI Test Plan Section 6.6.1):

- ❑ Agency Test Plan and Documentation Records
- ❑ Two (2) RSUs of each manufacturer to be tested
- ❑ Three (3) laptops
- ❑ Software test tools: Kapsch CVV Test Tool, CAMP Tools, etc.
- ❑ Bench test hand tools: pliers, screw drivers, socket set, etc.
- ❑ 110 VAC-to-12V DC Power supplies
- ❑ Assortment of CAT5 Ethernet patch cables (for connecting laptops to devices being tested)
- ❑ Wireshark Protocol Analyzer capable of decoding and logging SPaT, MAP and RTCM
- ❑ Survey equipment (e.g., Trimble R12 GNSS receiver and Trimble TSC3 data controller)
- ❑ Other relevant software tools used during device certification testing

Typical equipment for conducting field validation testing (see CI Test Plan Section 6.6.1):

- ❑ At least one vehicle with one OBU
- ❑ High framerate camera and associated software
- ❑ Laptop
- ❑ Assortment of CAT5 Ethernet patch cables (for connecting laptops to OBU device)
- ❑ Wireshark Protocol Analyzer capable of decoding and logging SPaT, MAP and RTCM
- ❑ Survey equipment (e.g., Trimble R12 GNSS receiver and Trimble TSC3 data controller)
- ❑ Other relevant software tools used during device certification testing