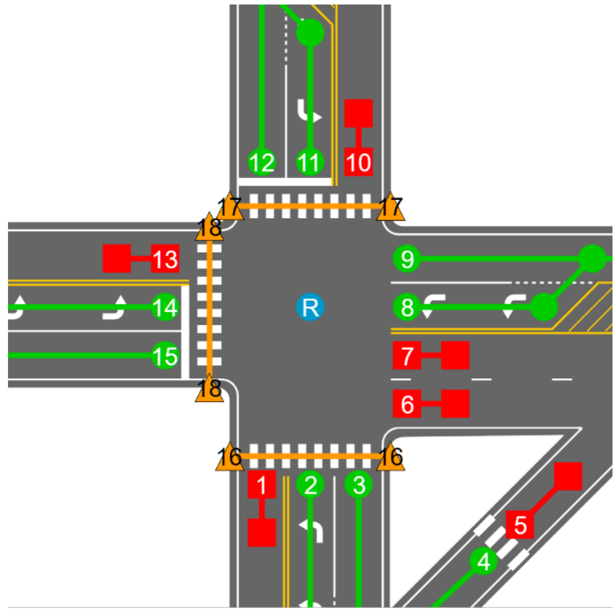


Guidance Document for MAP Message Preparation

FINAL – Revision #2
June 2023

Prepared for:
The Connected Vehicle Pooled Fund Study
(University of Virginia Center for Transportation Studies)

Prepared by:
Athey Creek Consultants, LLC and Synesis Partners, LLC

Contents

Revision Summary

Revision #1 was prepared and released in April 2022, approximately one year after the release of the original MAP Guidance Document. Revision #1 represents the influences of three key factors:

- **Completion of the CTI 4501 v01.00, Connected Intersections Implementation Guide.** The Connected Vehicle Pooled Fund Study (CV PFS) coordinated with the activities of the ITE/Connected Intersections project. As the CTI 4501 v01.00, Connected Intersections Implementation Guide was released, there were two MAP Guidelines that required revisions to remain consistent with the content of the CTI 4501 v01.00, Connected Intersections Implementation Guide. The guidance updated in this version include:
    - Guidance #3.12: First Node Point – Egress Lane (page 50);
    - Guidance #3.13: Length of Ingress Lane (page 51); and
    - Guidance #3.33: Multiple Intersections in Close Proximity (page 68).

- **Understanding of the use of Geodetic reference systems other than the World Geodetic System 84 (WGS 84).** Through industry testing, it is now understood that some errors observed in MAP message creation originate from the use of other geodetic reference systems (e.g., some use the North American Datum of 1983 (NAD 83) reference system). Therefore, a new guidance (Guidance #1.17) has been added that specifically describes the need to use the WGS 84 standard coordinate frame of reference or to convert to WGS 84. This update can be found on page 32.

- **The initiation of the SAE J2945/A Road Geometry Attributes (RGA) effort.** The Introduction section of this document now includes a description of the efforts underway by the Society of Automotive Engineers (SAE) to develop the RGA. The intent is to inform users of this document of the current activities of this SAE effort. This addition can be found on page 5.

Revision #2 was prepared and released in May 2023 to reflect increased information about MAP message creation and validation learned through CV PFS activities. Updates include:

- **Estimated level of effort.** A new section 1.4 was created for the Introduction to summarize the anticipated level of effort for creating MAP messages. This update can be found on page 6.

- **Updated resources.** The related resources provided in the Introduction was updated to reflect new resources that have been published since the initial version of this document, in some cases replacing earlier documents that had been listed. Note that a new version of the Connected Intersections Implementation Guide, which was described in the previous revision, has been released (i.e., CTI 4501 v01.01) and references to this document have been updated.

- **Clarified that the speed limit data element is required.** New guidance has been added to step 3, specifically Guidance #3.6, as well as supporting text elsewhere, to clearly state this.

- **Update of MAP accuracy, testing and validation activities.** Updates relate to improved node geometry accuracy (e.g., surveys or Lidar data collection), either when creating the MAP or performing accuracy testing; guidance on using new tools available to test MAP message completeness and format; and updated field validation guidance to be conducted when creating the MAP message or validating the connected intersection. The new or updated guidance in this version include:

- Guidance #3.8: Node Point Geometry and Attributes (page 46);
- Guidance #3.9: Node Point Accuracy (page 47);
- Guidance #5.2: Test MAP Message Completeness and Structure (new) (page 77);
- Guidance #7.1: Field Validation (page 79).

No other significant edits have been made to the MAP Creation Guidance.

1.0 Introduction

Transportation agencies in the past few years have started moving towards achieving connected intersections. Connected intersections broadcast signal phase and timing (SPaT) data, MAP message (intersection geometry), and position correction to vehicles.

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 connected intersection. On-board Units (OBUs) that receive and process data from connected intersections 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.

This document provides guidance on the creation of MAP messages to be used with corresponding SPaT messages for non-automated intersection approach and violation applications.

The ability for an OBU to interpret the SPaT data broadcast by any connected intersection relies on the companion MAP message. Further, the ability for an OBU to travel through various connected intersections operated by different IOOs, relies upon consistency in the MAP messages. Use of this *MAP Guidance Document* and successfully completing each step outlined in this document will help to ensure consistency across agencies. This document provides guidance on the creation of MAP messages to be used with corresponding SPaT messages for non-automated intersection approach and violation applications. The need driving this project was for connected vehicle applications to have consistent MAP messages using the available standards. Automated applications are not included in this guidance for various reasons, particularly lack of experience, wide variety of proprietary approaches, and limited understanding of how needs for automated applications at connected intersections differ from those of connected vehicle applications. The MAP messages resulting from this guidance may still be used by and benefit automated applications.

The guidance was developed based on research, reviews of technical resources, and interviews with transportation agencies that have created MAP messages.

1.1 Document Structure and Target Audience

This section describes the structure of the document and the target audience of the guidance for MAP message creation.

1.1.1 Document Structure

Following this document overview, the remainder of this section will present an overview of MAP messages and standards, define connected and non-connected intersections, describe the current state of practice for creating MAP messages, including the use of common tools, and identify related resources and activities.

Section 2 contains the guidelines categorized into 7 steps created by the Project Panel and supporting contractors. The Project Panel included a subset of the Connected Vehicle Pooled Fund Study members that provided input throughout the duration of the project and reviewed project deliverables.

Section 3 contains scenarios describing an overall summary of how the guidelines may be used to support the creation of MAP messages.

1.1.2 Target Audience

This document was created for:

- IOOs that are deploying or updating connected intersections and are responsible for creating MAP messages;
- Contractors that create MAP messages on behalf of IOOs;
- Service providers that are creating MAP messages in their role of operating applications or providing data to original equipment manufacturers (OEMs) or third-party data providers; and
- OEMs or after-market application developers that are creating OBUs to receive and process MAP messages.

1.2 MAP Message Overview and MAP Message Standard

This section provides an overview of MAP messages and the MAP message standard.

1.2.1 MAP Message Overview

Maps are needed to identify roadway geometry and features relative to a connected vehicle's location. Map data of interest could include road segment characteristics such as width and curvature, and intersection descriptions including lane movement assignments and paths. Traffic control information can then be related to those map features and data sets.

1.2.2 MAP Message Standard

The SAE J2735_202007 Vehicle-to-Everything (V2X) Communications Message Set Dictionary (SAE J2735) specifies a message set, and its data frames and data elements, for use by applications that use V2X communications systems. The dictionary includes a specification for map data among its message sets. The MapData (MAP) message is a standardized encoding of map data developed as part of the larger set and is designed to provide location references for other messages. Information about traffic signal controls, for example, is provided by a SPaT message that refers to the MAP message for lane assignments for signal phases.

An SAE J2735 MAP message is used to describe intersection and road geometries and associate those geometries with some agency data and vehicle class restrictions. Lane geometries are physically described using an ordered sequence of nodes (reference point offset distances or latitude/longitude coordinates) that convey the shape and width of the lane, speed limit, allowed maneuvers, and ingress/egress metadata.

The most common developments to date have been MAP messages for intersections in conjunction with SPaT messages. MAP messages locate the physical road geometry using the World Geodetic System (WGS) 84 coordinate system and node offsets. They can exist independently from SPaT messages but SPaT messages cannot operate without MAP messages that enable SPaT schedules to have meaning.

SAE J2735 specifies messages using Abstract Syntax Notation (ASN.1) so that the messages can be applied to a broad range of communication media. Early deployments of MAP message broadcast have used DSRC, but the use of ASN.1 specifications enables the same messages to be sent over other media such as cellular vehicle-to-everything (C-V2X) communications.

The standard further specifies the binary encoding rules that render the messages as bits for transmission. The first editions of SAE J2735 used basic encoding rules (BER), but it was determined that a more compact encoding was needed to keep message sizes within the DSRC standards. The most recent version uses unaligned packed encoding rules (UPER), which organize as much information into as few bits as possible.

The current SAE J2735 MAP message standard is tailored towards intersections. Recognizing the role of MAP messages and the need to support a broader set of connected vehicle applications, SAE is actively developing a new standard (SAE J2945/A) for a next generation description of roadway geometry attributes RGA to better support a variety of connected vehicle applications, including connected intersections, connected work zones, and others. The extent that SAE J2735 will be used by industry beyond the release of the RGA standard is not fully understood at this time. Currently, the SAE J2735 MAP message remains the standard for exchanging MAP data between the infrastructure and vehicles. However, readers of this guidance document should follow the progress of the SAE RGA standards activities.

1.2.3 Bounds of a Connected Intersection

Each connected intersection includes a set of ingress (inbound) and egress (outbound) lanes. The bounds of a connected intersection extend to the ends of each of these lanes.

1.3 MAP Messages for Connected and Non-Connected Intersections

This section provides a definition of connected intersections and non-connected intersections related to the creation of MAP messages.

1.3.1 MAP Messages for Connected Intersections

The Institute of Transportation Engineers (ITE) Connected Intersections project defined a connected intersection as an infrastructure system that broadcasts SPaT, mapping information, and optional position correction data to vehicles. Building upon this definition, each connected intersection must include a MAP message that is accurate, verified, and representative of the approaches and movements of the intersection. Additionally, connected intersection information may also be exchanged and processed by other users to enhance pedestrian and bicyclist safety, for example.

1.3.2 MAP Messages for Non-Connected Intersections

While a primary use of a MAP message is to be broadcast together with SPaT messages at connected intersections, there are situations where a MAP message could be created for non-connected intersections. A connected intersection, for example, might have an immediate upstream intersection that is not connected (i.e., equipped to broadcast SPaT and MAP) but is close enough that applications may benefit from having data for the ingress and egress lanes of the upstream intersection.

In these situations, nearby connected intersections may broadcast the MAP messages of other intersections.

1.4 Anticipated Level of Effort to Create MAP Messages

The level of effort to create MAP messages will necessarily vary based on a variety of factors.

- **Intersection complexity.** A more complex intersection with unique geometries (e.g., a skewed intersection with 6 lanes on each approach and horizontal curves on an approach) will require more time to create a MAP message than a simpler intersection. More time will also be needed to conduct a survey and drive through an intersection for field validation activities at a more complex intersection.
- **Expertise.** The experience of the MAP creator will influence the amount of time required. A first-time MAP creator will need to spend some time becoming familiar with the selected MAP creation tool or processes for field validation data collection and analysis, for instance.
- **Availability of data and imagery.** If the imagery of the intersection is current, then information like lane configuration, width, and geometry can be readily derived and used in a MAP creation tool like the ISD Message Creator (i.e., United States Department of Transportation (USDOT) Tool), as described in Section 1.5. If imagery is not up to date, an alternate approach and tools may be needed (e.g., receive construction plans or use a KML file), which may consume more time. The Utah Department of Transportation (DOT) has noted that using ArcGIS to create a MAP message when imagery is not current to use the USDOT Tool may take twice as long.
- **Intersection location.** Because some MAP creation activities like the field survey and validation require traveling to the field, an intersection that is closer to the office will require less staff time.
- **MAP message communication, storage, and archival.** The ease of communicating with the RSU to upload a new MAP message and access a storage location for archiving out-of-date MAP messages can reduce the level of effort. For example, the ability to remotely upload a MAP message to the RSU will reduce the level of effort compared to going to the field to upload it directly at the RSU. Likewise, when a revised MAP message is created, the previous MAP message should be archived for reference in case there are errors with the revised MAP message.
- **Number of MAP messages.** There may be some marginal gains in efficiency through creating and assessing requirements for multiple MAP messages at the same time, especially if each intersection is in the same general area. Efficiencies may be gained for MAP messages being created for multiple intersections in a corridor or localized area (e.g., conducting field validation activities of driving through multiple intersections in a single afternoon). That is, it is just as easy to perform any data preparation and setup needed for multiple intersections as it is for a single intersection. Similarly, it is more time efficient to assess each individual requirement for a batch of MAP messages at one time, than it is to assess all requirements for a single MAP message individually.
- **Automated processes.** The degree to which MAP creation and data analysis tools are automated increase efficiency. Requirements that can be verified using automated tools (e.g. CAMP SPaT/MAP Utility, as described in Section 1.5 below) get results much faster than those that do not have an automated process.

Table 1 includes an estimated level of effort to conduct the main activities for creating a MAP message based on Utah DOT's experience.

Table 1: Estimated Level of Effort to Create a MAP Message

Activity	Estimated Level of Effort
Creating the MAP Message	Using the USDOT ISD Tool: - 1.5-2 hours for the first MAP message - <1 hour for subsequent MAP messages, depending on intersection complexity *May take longer if current imagery is unavailable and a different MAP creation tool is used.*
Manual tool calibration, data editing, and office validation of created MAP message (e.g., tool address may not match the names, checking file size, visually checking MAP message output versus imagery available from various sources)	<1 hour
Field Survey (e.g., crosswalk and lane markings, included drone imagery)	1-2 hours per intersection
Field Validation Data Collection (e.g., ensuring RSU has received the MAP message correctly from download, setup test equipment, drive intersection with software to collect data)	- 1 hour for preparation and equipment setup - 2.5-3 hours per intersection for drive runs
Field Validation Data Analysis	2-4 hours per intersection

1.5 Tools for MAP Message Creation

The USDOT has developed and hosts a MAP message creation tool for SAE J2735, the ISD Message Creator (i.e., USDOT Tool). This tool allows a MAP creator to define the lanes and approaches of an intersection and place the nodes for ingress and egress lanes using a graphical interface and on-line map display. In addition, the tool also allows MAP creators to create the MAP message encoded as an ASN.1 UPER Hex string. USDOT offers technical support for the use of the USDOT Tool as well as technical questions about the creation of MAP messages. This technical support is available at: CAVSupportServices@dot.gov.

In addition to the USDOT Tool, MAP creators may use supporting tools such as on-line mapping solutions (e.g., Google Maps, Bing Maps, Apple Maps), Geographic Information Systems (GIS) solutions, and proprietary MAP creation tools available from contractors and system vendors.

Note that other tools are available to support MAP validation, including the CAMP SPaT/MAP Utility, described in the Connected Intersection MAP Data Assessment Supporting Basic Red Light Violation Warning document, and the Kapsch CV Test Tool.

1.6 Related Resources and Activities

A review of key documents related to MAP message creation was conducted to inform the development of this MAP preparation guidance. Collectively, these resources establish standards and identify clarifications covering the breadth of topics and scenarios that IOOs need to understand to support their creation and operation of MAP messages. The title and brief summary of these key documents are:

- **SAE J2735_202007 V2X Communications Message Set Dictionary (2020)**

This document is the standard describing the formatting and data exchange for application messages that use V2X, including MAP and its accompanying SPaT messages. While the data dictionary was originally designed for use over DSRC, this revised document is intended to be independent of the underlying communications protocols used to exchange data between participants in V2X applications. The content and structure of the MAP messages are defined by the SAE J2735 standard, which serves a critical role and is the basis for this MAP guidance document.

- **Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections Implementation Guide (2022)**
  Standardizes the key capabilities and interfaces for a connected intersection, addresses the ambiguities and gaps identified by early deployers, and provides guidance to generate messages and develop applications for signalized intersections that are truly interoperable across the United States.

- **Connected Vehicle Pooled Fund Study Connected Intersection Guidance (2023)**
  Provides guidance on the deployment and operations of connected intersections, and serves as a companion document to this MAP Guidance with supporting information.

- **Clarifications for Consistent Implementations (CCI) to Ensure National Interoperability: Connected Signalized Intersections, version 1.9.5 (2020)**
  This document identified 17 ambiguities related to connected signalized intersections that need to be clarified and agreed upon by IOOs and OEMs for infrastructure systems to successfully communicate with production vehicles. While only some of these are specific to MAP messages, they all should be understood and considered regarding the guidance document. These ambiguities were inputs to the CTI 4501 v01.01 Connected Intersections Implementation Guide, but this document remains a resource for IOOs to understand the ambiguities and history behind them.

- **SPaT Challenge Infrastructure System Model Concept of Operations, version 1.6 (2018), SPaT Challenge Infrastructure System Model Requirements (2018), SPaT Vehicle-to-Infrastructure (V2I) Interface for Red Light Violation Warning Concept of Operations, and SPaT V2I Interface for Red Light Violation Warning System Requirements Specification**
  The 2018 Concept of Operations (ConOps) document presents operational concepts and use cases for the MAP messages and defines the role of the MAP message in the context of a full SPaT Infrastructure System. Additionally, requirements are provided in a 2018 Model Requirements document. An updated version of the ConOps, together with an accompanying requirements document, was developed in 2020 and was reviewed in conjunction with these original documents. These additional documents are currently available on the Cooperative Automated Transportation (CAT) Coalition's website.

- **Vehicle to Everything (V2X) Hub MAP and SPaT Planning and Implementation Considerations**

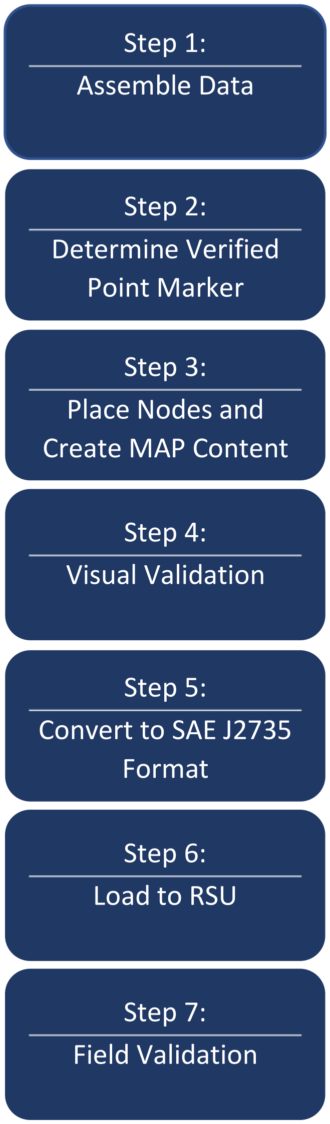
This document was created for users of the V2X Hub and includes a detailed description of the informational elements of the MAP messages and serves as a valuable supplement to the SAE J2735 standard.

- **MAP Message Testing Resources**
  Several resources are available to support testing and validation of MAP messages, including:
  - *Crash Avoidance Metrics Partners LLC (CAMP) SPaT/MAP Utility, version 1*. An on-line tool that allows the upload of JSON files and processes them to analyze SPaT and MAP messages, including analysis of the MAP message format to determine whether all required fields are populated.
  - *CAMP Connected Intersection MAP Utility Assessment Supporting Red Light Violation Warning version 0.90 (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 an OBU.
  - *CTI 4502 v01 Connected Intersections Validation Report (2022)*. Summarizes findings from the 2021 ITE Connected Intersection Program validation phase and includes information about the CAMP tools used to verify MAP messages.

Additionally, other resources that have been superseded by the Connected Intersection Implementation Guide and Connected Intersection Guidance listed above, but which also contain valuable reference information for practitioners include:

- **SPaT Challenge Infrastructure System Model Concept of Operations, version 1.6 (2018), SPaT Challenge Infrastructure System Model Requirements (2018), SPaT Vehicle-to-Infrastructure (V2I) Interface for Red Light Violation Warning Concept of Operations (2020), and SPaT V2I Interface for Red Light Violation Warning System Requirements Specification (2020)**
  The 2018 Concept of Operations (ConOps) document presents operational concepts and use cases for the MAP messages and defines the role of the MAP message in the context of a full SPaT Infrastructure System. Additionally, requirements are provided in a 2018 Model Requirements document. An updated version of the ConOps, together with an accompanying requirements document, was developed in 2020 and was reviewed in conjunction with these original documents. These additional documents are currently available on the Cooperative Automated Transportation (CAT) Coalition's website.

2.0 MAP Message Creation Guidance



Based on the research and interviews conducted with transportation agencies that have created MAP messages within this project, a series of seven steps were identified as common when creating MAP messages. The seven steps are as follows:

- Step 1: Assemble Data
- Step 2: Determine Verified Point Marker
- Step 3: Place Nodes and Create MAP Content
- Step 4: Visual Validation
- Step 5: Convert to SAE J2375 Format
- Step 6: Load to RSU
- Step 7: Field Validation

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

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

Table 2 provides a listing of the guidance that is described in this section for each of the seven steps.

It is important to note that practitioners may prefer to customize this process by consolidating or expanding these seven steps.

Table 2: Listing of MAP Guidance by MAP Creation Step

Step 1 – Assemble Data	
Guidance #1.1	Understanding of Minimum Required Elements of the MAP Message
Guidance #1.2	MAP Message and Intersection Revision Counters
Guidance #1.3	Intersection Reference Identification (ID): Road Regulator ID
Guidance #1.4	Intersection Reference ID: Intersection ID
Guidance #1.5	Intersection Geometry
Guidance #1.6	Lane Width
Guidance #1.7	Lane ID
Guidance #1.8	Direction of Travel
Guidance #1.9	Connections Between Motor Vehicle Lanes
Guidance #1.10	Crosswalk Lanes
Guidance #1.11	Connections Between Sidewalk Lanes (Pedestrian Landings) and Crosswalk Lanes
Guidance #1.12	Phase Numbering and Signal Groups
Guidance #1.13	Lane Use Variations
Guidance #1.14	Reference Point
Guidance #1.15	Computed Lanes
Guidance #1.16	Allowed Lane Maneuvers
Guidance #1.17	Geodetic Reference Systems
Step 2 – Determine Verified Point Market	
Guidance #2.1	Selection of a Verified Point Marker
Guidance #2.2	Precision of the Verified Point Marker Coordinates
Guidance #2.3	Determination and Implementation of Displacement Distance/Direction
Step 3 – Place Nodes and Create MAP Content	
Intersection Descriptors	
Guidance #3.1	Incrementing MAP Message Revision Counter
Guidance #3.2	Intersection Reference ID and Road Regulator ID
Guidance #3.3	Incrementing Intersection Geometry Revision Counter
Guidance #3.4	Reference Point
Intersection Lane Geometry	
Guidance #3.5	Lane Width
Guidance #3.6	Speed Limits
Guidance #3.7	Lane ID
Guidance #3.8	Node Point Geometry and Attributes
Guidance #3.9	Node Point Accuracy
Guidance #3.10	Node Point Precision
Guidance #3.11	First Node Point – Ingress Lane
Guidance #3.12	First Node Point – Egress Lane
Guidance #3.13	Length of Ingress Lane
Guidance #3.14	Length of Egress Lane
Guidance #3.15	Node Spacing in Vertical Curves

2.1 Step 1 - Assemble Data

Step 1:
Assemble Data

The MAP message creation process can proceed quickly when all the needed information is available, especially in situations when a comprehensive MAP creation tool (e.g., the USDOT Tool or a vendor tool) is used. Later steps in creating a MAP message will likely require information and/or data from multiple offices or groups within a transportation agency. Therefore, this step is focused on preparation to enable the MAP creator to efficiently create a MAP message.

2.1.1 Objective

The objective of Step 1 – Assemble Data is to assemble the specific data and information needed as input for generating MAP messages.

To assemble the data for Step 1, the data and information needs to be obtained from an authoritative source, needs to be current, and an understanding of the data and role in MAP creation is needed.

2.1.2 Step 1 Guidance

MAP creators are encouraged to assemble the data elements noted in Table 3 during Step 1 to support later steps of the MAP creation process. As part of this step, MAP creators should consider the specific goal of the connected intersection deployment, including any local applications that may be supported (e.g., transit signal priority) when determining what additional, optional data elements to include.

Table 3: Step 1 - Assemble Data: Guidance List

Step 1 - Assemble Data	Guidance #1.1	Understanding of Minimum Required Elements of the MAP Message
	Guidance #1.2	MAP Message and Intersection Revision Counters
	Guidance #1.3	Intersection Reference ID: Road Regulator ID
	Guidance #1.4	Intersection Reference ID: Intersection ID
	Guidance #1.5	Intersection Geometry
	Guidance #1.6	Lane Width
	Guidance #1.7	Lane ID
	Guidance #1.8	Direction of Travel
	Guidance #1.9	Connections Between Motor Vehicle Lanes
	Guidance #1.10	Crosswalk Lanes
	Guidance #1.11	Connections Between Sidewalk Lanes (Pedestrian Landings) and Crosswalk Lanes
	Guidance #1.12	Phase Numbering and Signal Groups
	Guidance #1.13	Lane Use Variations
	Guidance #1.14	Reference Point
	Guidance #1.15	Computed Lanes
	Guidance #1.16	Allowed Lane Maneuvers
	Guidance #1.17:	Geodetic Reference Systems

The following subsections provide guidance in assembling each data element.

2.1.2.1 Step 1 - Guidance #1.1: Understanding of Minimum Required Elements of the MAP Message

During Step 1 – Assemble Data, MAP creators should become familiar with the minimum required elements of the MAP message. MAP creators using a tool for creating the MAP message will likely be assisted in creating most, if not all, of the required elements. There are two levels of element requirements, including:

- Those elements identified in SAE J2735 as mandatory for a valid SAE J2735 message to support in-vehicle applications of production vehicles; and
- Additional MAP message elements recommended as required based on industry experience and anticipated applications use of the MAP messages.

J2735 Minimum Required Elements

The SAE J2735 MAP message (within the standard and message denoted as the MSG_MapData) contains several sets of data elements, which may themselves contain further sets of elements. At the topmost level, the required element is the revision number for the MapData (msgIssueRevision). The intersections and road segments elements are optional within the standard, but for the purposes of this guidance document, at least one intersection (IntersectionGeometry) or one road segment (RoadSegments) should be created.

The data elements required for intersections (IntersectionGeometry) and road segments (RoadSegments) are basically identical. They are an ID, a revision number, a reference point (refPoint), and a set of lanes (laneset/roadLaneSet) comprising the lane definitions for the intersection or road segment. Each laneset/roadLaneSet may contain 1 to 255 lane (GenericLane) definitions. The required fields for a GenericLane are an ID (laneID); attributes applicable to the lane (laneAttributes) including direction of travel, sharing of lanes by travel modes, and lane type (for example, to distinguish vehicle lanes from crosswalks; and the list of nodes (nodeList) defining the lane-center path geometry.

Additional MAP Message Elements Recommended as Required

From review of the optional elements in SAE J2735, and considering the resources reviewed through this project, it is recommended that a number of optional elements be considered mandatory by this guidance document for creating a MAP message as described below.

Elements General to the Intersection

- **intersections (Intersection Geometry)**
  Data about intersection geometry is essential for MAP messages in the context of this document.

  Basis:
  A MAP message must contain the intersection lane geometry and location so that a vehicle can determine its own location in relation to the intersection lanes and stop line.

- **region (Road Regulator Identifier)**
  This data element is within the intersection reference identifier and is used in conjunction with the Intersection Identifier to uniquely describe an intersection.

Basis:
This value supports the intersection identifier to support the vehicle in uniquely identifying the intersection in order to associate the correct data.

- **laneWidth (Lane Width)**
  The laneWidth data element is specified within IntersectionGeometry and RoadSegment. Its value represents the most common lane width for the geometry being defined.

  Basis:
  This guidance recommends specifying the laneWidth so that paths can be defined as completely as possible. Most applications need to determine lane width, so it makes sense to include it upfront. Feedback from application developers has indicated that the lane width is used to locate the lane the vehicle is traveling.

Elements Related to Specific Lanes

- **maneuvers (Lane Maneuvers)**
  This data element is used to identify each lane maneuver that is allowed for that lane at the stop line for ingress lanes and at the downstream lane end point for egress lanes. The maneuvers defined in SAE J2735 are a combination of movements (e.g., a left turn movement is allowed in this lane, a right turn movement is allowed in this lane, a straight movement is allowed in this lane) and control at the intersection (e.g., right turn on red allowed, U turn movement is allowed in this lane).

  Basis:
  This guidance recommends including this data element in order to identify conflicting movements, such as crosswalks that may have pedestrians.

- **connectsTo (Lane Connections)**
  The connectsTo data frame lists the connection relationships between lanes. The interior of an intersection is generally not modeled by lanes, so the connectsTo data frame is used to define the relationship between ingress and egress lanes and allowed maneuvers. This data element also specifies the signal group (signalGroup) data, which relates the lane to a signal group of a SPaT message.

  Basis:
  This data frame is required to include several data elements that are recommended for inclusion to the MAP message based on feedback from early deployments suggesting that these data elements are valuable.

Elements specific to Connections (between lanes)

- **maneuvers (Connection Maneuvers)**
  This data element describes each connection between an ingress lane and an egress lane to identify the maneuver that the connection allows.

Basis:
This data element is required to support lane connections for identifying allowed maneuvers from each ingress lane to respective egress lanes.

- **remoteIntersection (Remote Intersection Reference Identifier)**
  This data element is required when a lane connects to a lane defined for an adjacent SPaT-enabled intersection, in order to provide the intersection reference identifier of the remote intersection.

  Basis:
  Showing a connection in the MAP message between an egress lane and an ingress lane of an adjacent intersection allows vehicles to know the intersection reference ID of the next intersection it will encounter. This can aid the vehicle in situations where it may be in range of broadcasts from multiple SPaT-enabled intersections.

- **signalGroup (Connection Signal Group)**
  This data element notes each connection between an ingress lane and an egress lane to identify the SPaT signal group that provides traffic signal control for that movement.

  Basis:
  It is critical that applications identify the signal group representing their path of travel in order to properly interpret the SPaT message.

Summary of Minimum Required Elements

Table 4 summarizes the recommended guidance for each data frame and data element for the MAP message that are presented in more detail in the following subsections, which provide guidance in assembling each data element. While SAE J2735 marks several data items to be optional, the recommended guidance is to require the data frames and data elements as described in Table 4 below. The organizational structure of these data are shown in Appendix A.

Table 4: Guidance regarding inclusion of data elements and data frames into MAP messages

MAP Message Element	Identified as Optional or Required		Related Guidance in this Document
	SAE J2735	This Document	
MAP Message Revision Counter Increment	Required	Required	• Guidance #1.2 MAP Message and Intersection Revision Counters • Guidance #3.1 Incrementing MAP Message Revision Counter
Intersection Geometry Information	Optional	Required	• Guidance #1.5: Intersection Geometry
Road Regulator Identifier	Optional	Required	• Guidance #1.3 Road Regulator ID • Guidance #3.2 Intersection Reference ID and Road Regulator ID

MAP Message Element	Identified as Optional or Required		Related Guidance in this Document
	SAE J2735	This Document	
Intersection Identifier	Required	Required	• Guidance #1.4 Intersection ID • Guidance #3.2 Intersection Reference ID and Road Regulator ID
Intersection Revision Counter Increment	Required	Required	• Guidance #1.2 MAP Message and Intersection Revision Counters • Guidance #3.3: Incrementing Intersection Geometry Revision Counter
Intersection Reference Point	Required	Required	• Guidance #1.14: Reference Point • Guidance #3.4: Reference Point
Lane Width	Optional	Required	• Guidance #1.6: Lane Width • Guidance #3.5: Lane Width
Speed Limit	Optional	Required	• Guidance #1.5: Intersection Geometry • Guidance #3.6: Speed Limits
Lane Identifier	Required	Required	• Guidance #1.7: Lane ID • Guidance #1.10: Crosswalks • Guidance #3.7: Lane ID
Direction of Travel	Required	Required	• Guidance #1.8: Direction of Travel • Guidance #3.26: Direction of Travel
Revocable Lanes	Required	Required	• Guidance #1.13: Lane Use Variations • Guidance #3.27: Lane Use Variations
Lane Type	Required	Required	• Guidance #1.5: Intersection Geometry • Guidance #1.10: Crosswalk Lanes • Guidance #3.28: Lane Types
Lane Maneuvers	Optional	Required	• Guidance #1.16: Allowed Lane Maneuvers • Guidance #3.31: Allowed Lane Maneuvers
Node Point Geometry	Required	Required	• Guidance #3.8: Node Point Geometry and Attributes
Node Offsets	Required	Required	• Guidance #3.21: Node Offsets
Node Points	Required	Required	• Guidance #1.5: Intersection Geometry • Guidance #3.8: Node Point Geometry and Attributes • Guidance #1.9: Connections Between Motor Vehicle Lanes • Guidance #1.10: Crosswalk Lanes • Guidance #1.11: Connections Between Sidewalk Lanes (Pedestrian Landings) and Crosswalk Lanes
Lane Connections	Optional	Required	
Connection: *Connecting Lane*	Required	Required	
Connection: *Connecting Lane Maneuvers*	Optional	Required	
Connection:	Optional	Required*	

<table>
<tr><th rowspan="2">MAP Message Element</th><th colspan="2">Identified as Optional or Required</th><th rowspan="2">Related Guidance in this Document</th></tr>
<tr><th>SAE J2735</th><th>This Document</th></tr>
<tr><td>Remote Intersection Reference Identifier</td><td></td><td></td><td rowspan="2">• Guidance #1.12: Phase Numbering and Signal Groups
• Guidance #3.29: Defining Connections and Maneuvers – Motor Vehicle Lanes
• Guidance #3.30: Defining Connections and Maneuvers – Sidewalk Lanes to Crosswalk Lanes</td></tr>
<tr><td>Connection: Signal Group</td><td>Optional</td><td>Required</td></tr>
</table>

**Note: Remote Intersection ID is a required field only for adjacent downstream intersections that are connected.*

This understanding of the required and optional data elements in the MAP message will benefit the MAP creator with subsequent guidance presented below.

2.1.2.2 Step 1 - Guidance #1.2: MAP Message and Intersection Revision Counters

The MAP message includes two counters (i.e., values that increase by one each time a revision is made). The counters are used because vehicles with on-board applications often drive the same intersections frequently and may choose to store MAP content about an intersection within the application. This would then allow the application to receive a MAP message for a specific intersection with a revision counter that has not increased since the last time it was received and avoid needing to reprocess the MAP data.

The two counters that are included are as follows:

- *A MAP Message revision counter.* This counter is incremented by one every time any data element in the MAP message changes, except the time stamp.
- *An Intersection revision counter.* This counter is incremented every time an element describing an intersection changes except the time stamp. In situations where two or more intersections are described, it is possible that only one intersection would be changed.

Most MAP messages will describe only one intersection and typically the message revision counter and intersection revision counters will have the same increment number.

During Step 1 – Assemble Data, any previous MAP messages that may have been created for the intersection should be identified in order to understand whether this is the first MAP message created for the intersection or if the revision number included in the previous MAP message needs to be incremented by the value of one (1). The revision number value will increase by one, even if a major intersection reconstruction results in a drastically changed intersection, as long as the intersection reference ID was used in the previous MAP it would increment. This is a function that MAP creators should be looking for in MAP creation tools.

In situations where one MAP message represents multiple intersections, the MAP creator would need to understand the revision numbers of the intersections.

Guidance:

- During Step 1, clarify if there is only one intersection represented by the MAP message. If two or more intersections are represented, understand the revision status of each.
- During Step 1, identify whether any MAP message has previously been created for the intersection as this will be needed to increase the revision number by one, so long as the same intersection reference IDs are being used.
- Recognize that if the agency updates time stamps on the MAP message without changing the content of the message, the revision counters do not increment.

Basis:

- As per the SAE J2735 standard.

2.1.2.3 Intersection Reference ID

The Intersection Reference ID (combined Road Regulator ID and Intersection ID) is how OBUs ensure that they are processing the MAP and SPaT message for the same intersection. It is critical that the combination of these two data elements be unique to any other intersections.

During Step 1, it is important to gain understanding of the numbering approach that the MAP creator will use when creating the MAP messages.

2.1.2.3.1 Step 1 - Guidance #1.3: Road Regulator ID

The road regulator identifier (ID) portion of the Intersection Reference ID identifies the agency that regulates or operates the intersection controls. The road regulator ID is defined as two bytes storing values from 0 to 65535 (0 is reserved for testing).

Guidance:

- Determine the Road Regulator ID that is to be assigned for each intersection prior to creating the MAP message and ensure that the MAP message Road Regulator ID matches that of the SPaT message.
- Follow national/international progress on defining an overall strategy and numbering approach for Road Regulator ID. Activities of the Geographic Names Information System (GNIS) is referenced in the most recent version of the SAE J2735 standard (November 2022).
- The combination of each road regulator identifier and intersection identifier must be a unique value (not used by other intersections) and values 1 to 65535 are possible for the road regulator ID.

Basis:

- Attempts to preempt a national/international strategy with an intermediate approach would be replaced when a future numbering approach is defined.

2.1.2.3.2 Step 1 - Guidance #1.4: Intersection ID

The intersection identifier portion of the Intersection Reference ID is defined as two bytes storing values from 0 to 65535 (values 0 to 255 are reserved for testing). Large cities may have more than 65,000 intersections, if non-signalized intersections are included.

Guidance:

- During Step 1, determine the Intersection ID that is to be assigned for each intersection when creating the MAP message and ensure that the Intersection ID is assigned for each intersection and that the MAP message Intersection ID matches that of the SPaT message.
- Develop a local numbering approach (or use a numbering approach that has already been developed (such as by the traffic signals group in the agency)) that can be used to create unique intersection reference identifiers for each intersection.
- The fact that the OBUs will receive both a road regulator ID and an intersection ID will allow the OBU to consider these two values (e.g., concatenate them together) to properly identify intersections.
- The combination of road regulator ID and intersection ID in a MAP message must be unique and specific to a particular intersection. Within a given agency (road regulator) road network, each intersection ID must be unique.

Basis:

- As per the SAE J2735 standard.

2.1.2.4 Step 1 - Guidance #1.5: Intersection Geometry

Information describing each ingress lane into the intersection and each egress lane out of the intersection will be used when creating the MAP message. During Step 1 – Assemble Data, it is recommended that MAP creators assemble and understand this information. Information to understand and assemble for each intersection includes:

- All motor vehicle approaches and lanes (i.e., ingress and egress lanes).
- Crosswalk lanes at the intersection.
- Sidewalk lanes that represent pedestrian landings at the curbs near crosswalks (see guidance on crosswalks (Section 2.3.3.2.18) for more details).
- Stop lines – whether painted stop lines are used or when painted stop lines do not exist.
- Lane assignment (i.e., understanding of allowed maneuvers for each ingress lane, e.g., through only, exclusive left-turn, etc.).
- Presence and length of turn bays.
- Speed limit for each approach.

Assembling the resources in Step 1 will support later activities. For example, there is not one action in Step 3 – Place Nodes and Create MAP Content to enter intersection geometry, but rather there are various actions in Step 3 where the intersection geometry will be added to the MAP message content (e.g., First

Node Point – Ingress Lane, First Node Point – Egress Lane, Length of Ingress Lane, Length of Egress Lane, etc.).

Guidance:

Intersection geometry and control information may be obtained from a variety of sources and will be required during Step 3 – Place Nodes and Create MAP Content, as the MAP content is created. Typically, this data and information will be available through intersection control diagrams and signal timing plans. Other sources include:

- Screenshots or exports from central signal control software interfaces.
- Online mapping solutions with aerial imagery such as Bing Maps or Google Maps.
- GIS outputs.
- Survey grade mapping.
- Imagery captured from Unmanned Aerial Systems (UASs), also referred to as drones, where drone flying is allowed.
- As-built drawings.
- Roadway design documents for intersections that are not yet constructed or operational.
- Speed limit information to determine both reference speed limits and delta speed limit values. Note that the MAP message will contain one reference speed limit for each intersection. This will be the assigned speed limit for each lane and node unless a lane/node has a delta value assigned to it, indicating a change from the reference speed. For example, one road traveling through an intersection may have a speed limit of 55 mph, while the cross traffic road may have a speed limit of 35 mph. One speed limit will need to be assigned as the reference speed limit, and the other will be defined by the delta value (20 mph in this case). It is also possible for a lane to have a change in speed limit. For example the roadway speed may be 40 mph, but as the lane approaches the intersection, it may change to 30 mph. If the ingress lane extends into the segment of road that is 40 mph, a delta value would be used at the node point where the speed limit change occurs.

Basis:

- Input and feedback from interviews conducted with transportation agencies that have created MAP messages.

2.1.2.5 Step 1 - Guidance #1.6: Lane Width

The lane width element in the MAP message contains one value to represent the width of all lanes in the intersection, including ingress lanes, egress lanes, crosswalks, and bike lanes. The lane width element is used by nodes as a reference lane width. A lane width deviation (also referred to as a delta value) may be applied to adjust the lane width value for each node. For example, an intersection with similar and regular lanes widths can use the reference lane width value (e.g., 300 cm) for all lanes, while another intersection having dedicated bike lanes would reduce the lane width at the first node of the bike lane by including a deviation value for the bike lane (e.g., -200 cm). If a deviation value is assigned to the first node of a lane and the lane has a consistent width, that deviation value should not be repeated on any subsequent node.

Guidance:

- During Step 1, determine the most common lane width of the ingress and egress lanes to be used as the lane width value.
- Determine if any ingress/egress lanes differ from the reference lane width value by 0.2 meters or more and assemble these values for use in Step 3 – Place Nodes and Create MAP Content.
- Differences less than 0.2 meters should not be entered as deviations from the reference lane width.
- It is strongly recommended that the lane width value source should be based on IOO-verified sources for the lane width (e.g., design document, as-built, surveys, LiDAR-recorded data, etc.).
- If trusted sources for measurements of lane widths are not possible, lane width values may be approximated using an online mapping resource if this solution is acceptable for local applications, but this is not recommended as a primary or default solution.
- IOOs should only enter node point deviations if verified sources are available.
- Once a node point deviation is entered for the first node of a lane, only include additional deviation values if the lane width of subsequent nodes differs from the first node of the lane.
- Use the most common lane width for the reference lane width.
- Measure lane width from centerline of painted stripes, when available. Guidance on lane width determination (including guidelines for outside lanes) can be found in the Model Inventory of Roadway Elements.

Basis:

- The ninth bullet above advises MAP creators to perform physical measurements of lane widths to be input into the MAP Creation Tool being used because current online mapping and digital imagery solutions that require users to click on two lane lines to compute a distance will likely return inaccurate lane widths that are critical to vehicle lane determination).
- Calculating and determining an accurate lane width at the location of each node is not practicable for all IOOs.
- There is a trade-off between MAP message size, processing required to interpret the MAP message, and accuracy needed by the applications. The minimum of 20 cm deviation addresses this trade-off.

2.1.2.6 Step 1 - Guidance #1.7: Lane ID

Each lane at a connected signalized intersection must have an identifier that is unique for the intersection. During Step 3 – Place Nodes and Create MAP Content, the MAP creator will need to enter lane ID values for each lane. During Step 1, the MAP creator should familiarize themselves with any agency approach for consistency in selecting lane IDs. For example, an agency may decide to begin lane numbering with the southbound egress lane from the intersection as #1 and continue numbering the lanes in a counter-clockwise order around the intersection. This example of a lane numbering approach is illustrated in Figure 1.

There is no national approach for lane numbering, nor is there a need for consistency between intersections or agencies. However, consistency within an agency may be desired.

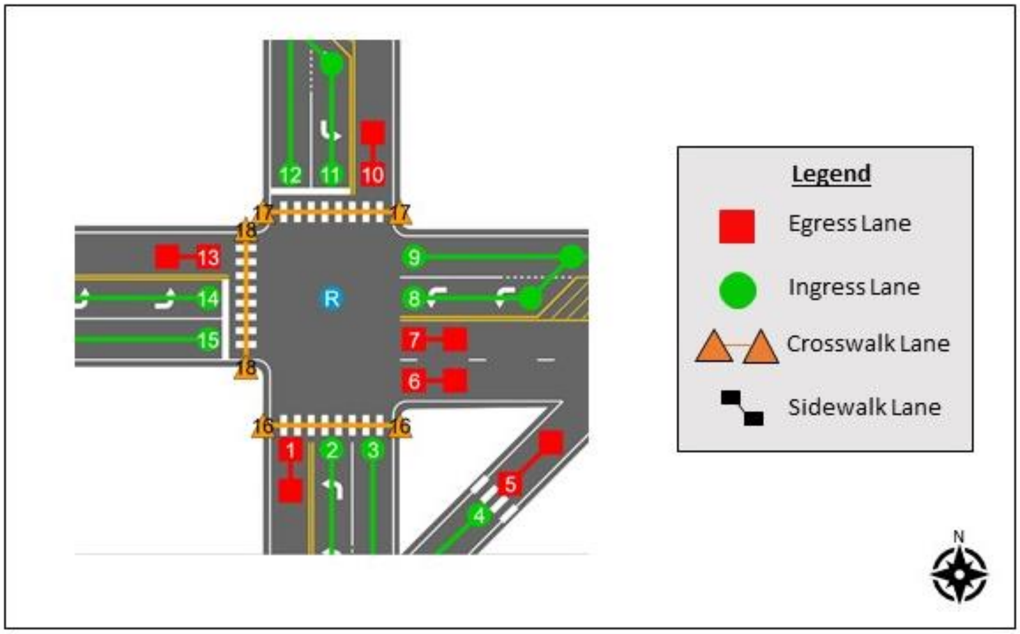


Figure 1: Illustration of example lane ID numbering approach
Source: Athey Creek Consultants and Synesis Partners

<u>Guidance</u>:

- Lane identifiers must be numerical whole values, between 1 and 254, inclusive.
- There are no pre-defined patterns for creating lane identifiers, but each agency is recommended to follow a consistent pattern for all intersections (e.g., start with the curbside, south-bound egress lane, and number sequentially in a counter-clockwise order).
- Lane identifiers will also need to be defined for crosswalks and sidewalk lanes. Each agency should identify an approach. Suggested approach is to begin numbering crosswalks as one value higher than the highest value of a motor vehicle lane and to begin numbering sidewalks as one value higher than the highest value of a crosswalk.

<u>Basis</u>:

- SAE J2735 requires 1-byte integer values.
- SAE J2735 identifies that the value 0 shall be used when the lane ID is not available or not known.
- SAE J2735 identifies that the value 255 is reserved for future use.

2.1.2.7 Step 1 - Guidance #1.8: Direction of Travel

The direction of travel (Lane Direction) for each lane must be described in the MAP message. This value may be used by an OBU to determine the lane of travel and/or to identify wrong way operations.

Guidance:

- During Step 1, the MAP creator should familiarize themselves with the direction of travel for each lane. In Step 3 – Place Nodes and Create Map Content, the MAP creator will need to place the nodes of lanes to respect the direction of travel.
- During Step 1, the MAP creator should identify any lanes that support bi-directional travel (two-way lanes), note that these would include reversible lanes.
- Crosswalk lanes and sidewalk lanes will also be assigned as bi-directional travel lanes.

Basis:

- As per the SAE J2735 standard.

2.1.2.8 Step 1 - Guidance #1.9: Connections Between Motor Vehicle Lanes

The data in the SPaT message will define the current signal state and status for each signal group operated by the controller. For a device receiving both the MAP message and SPaT message to understand which signal group is associated with their path of travel, each MAP message connection (e.g., a connection between one ingress lane and one egress lane) is assigned to the appropriate signal group. It is important that all possible connections are defined (e.g., a through lane may connect to the through egress lane as well as the right turn egress lane). More details will be described on this in Step 3 – Place Nodes and Create MAP Content.

Guidance:

- When assembling the data in Step 1 that will be used in Step 3 to create MAP messages, use care to understand all connections between ingress and egress lanes (e.g., protected turns, permissive turns, etc.).

Basis:

- During the future Step 3, when creating the MAP content, the MAP creator will need to identify all legal intersection movements. This includes consideration of legal U-turn movements from a left-turn lane, for example. Preparation in Step 1 will help ensure the MAP creator does not omit any connections.
- Specifying the connections between ingress and egress lanes is required as part of a complete intersection map description for use in conjunction with SPaT messages.
- Assembling information about connections will support MAP content creation in Step 3.

2.1.2.9 Step 1 - Guidance #1.10: Crosswalk Lanes

> ! This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

Crosswalks are defined in the MAP message as pedestrian crosswalk lanes. Applications may use the boundaries defined by the crosswalk lane to issue warnings to drivers when pedestrians are (or may be) in the crosswalk or to advise when protected crosswalk movements are active (e.g., a "walk" indication). Crosswalks defined in the MAP message may be also used by applications to provide information to pedestrians about the allowed movements from the curb into the crosswalk.

There are two aspects of crosswalks that must be understood during Step 1 to properly develop the crosswalks in the MAP messages in Step 3 – Place Nodes and Create MAP Content:

- ***Pedestrian crosswalk lanes*** – These are the lanes defining the areas designated for pedestrians to cross the road, particularly during pedestrian signal indications (e.g., "walk").
- ***Sidewalk lanes defining pedestrian landings*** – Sidewalk lanes, also referred to as pedestrian landings, can be used for various sidewalk geometries. Regarding crosswalks, sidewalk lanes are used to describe locations on the curb where pedestrians will be located prior to their entry into the crosswalk lane. A pedestrian signal advises pedestrians that they can maneuver from the sidewalk lane to the crosswalk (i.e., a "walk" sign indicates it is safe for the pedestrian to step from the curb into the crosswalk and begin crossing the road), therefore the sidewalk lane serves as a type of ingress lane and the crosswalk lane serves as an egress lane for connections defining pedestrian movements.

See Figure 2 for an illustration of crosswalk lanes and sidewalk lanes.

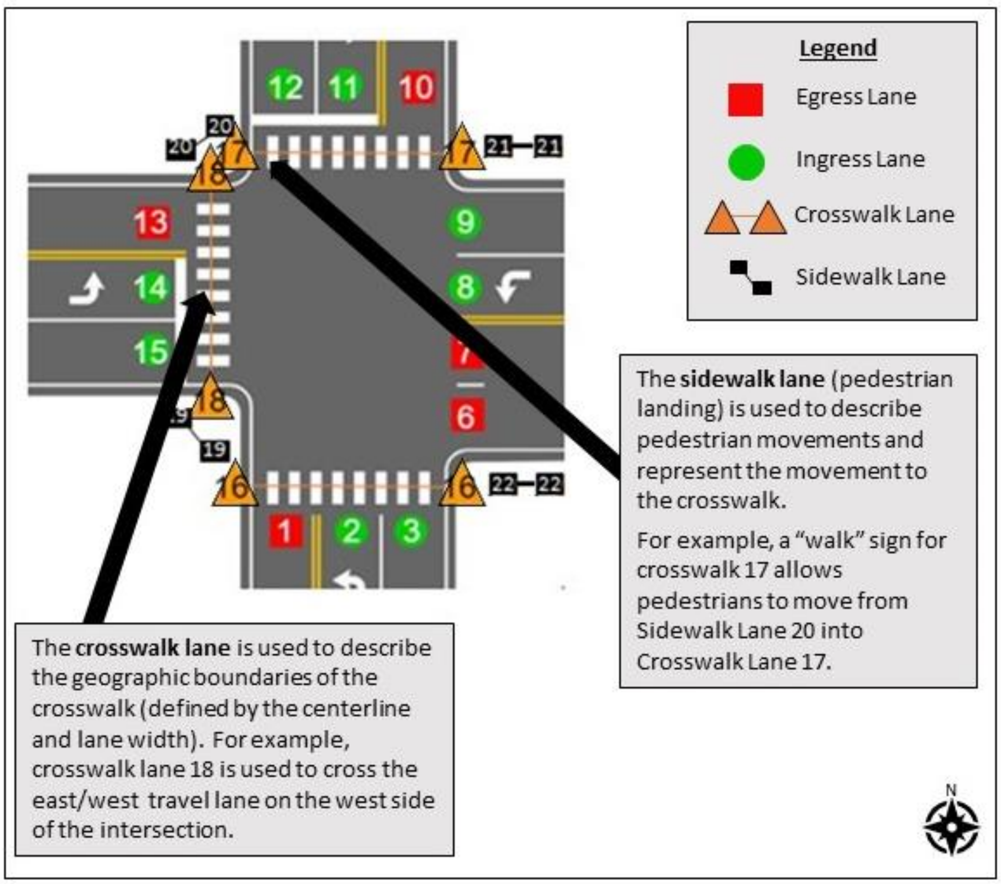


Figure 2: Illustration of crosswalk lanes and sidewalk lanes
Source: Athey Creek Consultants and Synesis Partners

Guidance:

- During Step 1, the location of the centerline of striped crosswalk lanes should be understood, as well as the width of each crosswalk. Each crosswalk lane will be defined by two coordinates, representing the centerline ends of the crosswalk (i.e., where the crosswalk meets the curb).
- Each crosswalk lane will need to be assigned a number, therefore activities in Step 1 should understand the agency approach to numbering crosswalks. In lieu of an agency approach to numbering crosswalk lanes, it is recommended to continue numbering by incrementing one number above the highest numbered motor vehicle lane for crosswalk lanes.
- During Step 1, MAP creators should understand where each sidewalk lane (acting as a pedestrian landing) will occur and assign numbers to the sidewalk lanes. Each sidewalk lane will need to be described by at least two node points and the coordinates of these node points should be the same as the coordinates of the start/end points of the crosswalk lane.
- In lieu of an agency approach to numbering sidewalk lanes, it is recommended to continue numbering by incrementing one number above the highest numbered crosswalk lane.
- When crosswalks include a median divider (i.e., a place for pedestrians to stop in the median before crossing the remainder of the road) with a walk sign activation button, MAP creators are encouraged to consider if two crosswalks should be coded to represent the entire crossing of the road and each assigned to the appropriate signal group controlling the movement.

Basis:

- Based on SAE J2735 standards.
- Based on requirements in the CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.1.2.10 Step 1 - Guidance #1.11: Connections Between Sidewalk Lanes (Pedestrian Landings) and Crosswalk Lanes

Connections from sidewalk lanes (pedestrian landings) to crosswalk lanes identify locations where pedestrians can move from the pedestrian landing (sidewalk lane) into the crosswalk lane and allow for these connections to be assigned to the appropriate signal group. By assigning a connection between a sidewalk lane and a crosswalk lane to a signal group, this will allow the “walk” indications described in the SPaT message to be related to the appropriate movement from sidewalk lane to crosswalk lane.

> ! This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

Guidance:

- When assembling the data in Step 1 that will be used in Step 3 to create MAP messages, use care to understand all pedestrian signals, crosswalks, and pedestrian landings (to be coded as sidewalk lanes). Specifically, ensure that connections between sidewalk lanes (pedestrian landings) and the crosswalk lanes are understood.

Basis:

- During the future Step 3, when creating the MAP content, the MAP creator will need to identify the starting and ending nodes of the sidewalk lanes and crosswalk lanes (see Figure 3). Preparation in Step 1 will help ensure the MAP creator does not omit any connections.
- Specifying the connections from sidewalk lanes to crosswalk lanes is required as part of a complete intersection map description for use in conjunction with SPaT messages.
- Assembling information about connections will support MAP content creation in Step 3.

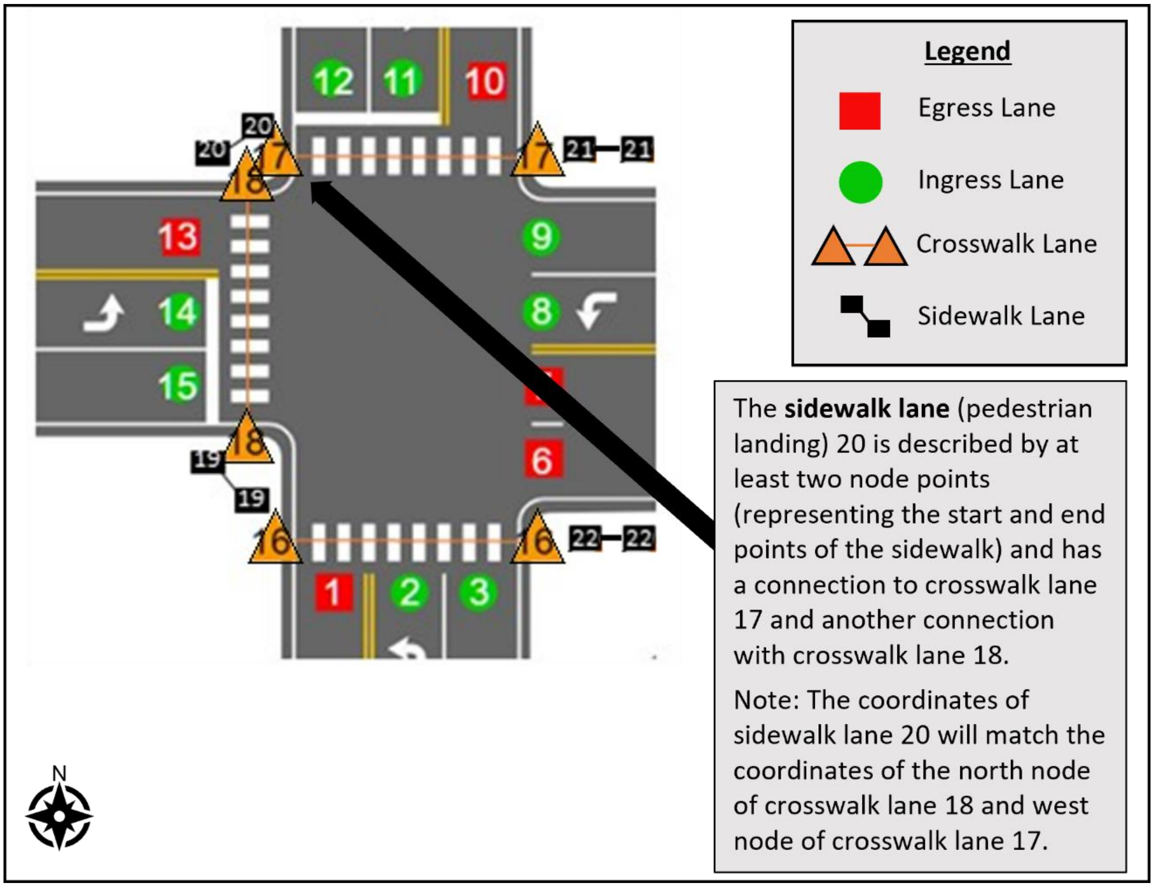


Figure 3: Illustration of node placement for crosswalk and sidewalk lanes
Drawing source: Athey Creek Consultants and Synesis Partners

2.1.2.11 Step 1 - Guidance #1.12: Phase Numbering and Signal Groups

The SPaT message that is broadcast together with the MAP message will provide information about the current signal indications. This is done by identifying a series of signal groups and then describing the state of each signal group. The MAP message makes it possible for applications receiving the SPaT message to understand what signal group applies to the imminent movement through the intersection. To do this, the MAP message will define a series of connections and also must identify the appropriate signal group that matches the connection. The signal group is not always the same number as the signal phase, and it is important in Step 1 – Assemble Data for the MAP creator to understand which signal group numbers relate to each connection.

To be prepared to create this information in Step 3 – Place Nodes and Create MAP Content, the MAP creator needs to assemble information about the signal phases, signal groups, and allowable vehicle movements during Step 1. Specifically, the information that is needed is as follows:

- ***The movements for each of the intersection phases.*** These are generally depicted by a signal phase diagram or represented in a signal timing plan. For example, in Figure 4 below, the northbound left-turn movement is Phase 1. The southbound through movement (with associated permitted right turn) is Phase 2.
- ***Information about any movements that are allowed using overlaps***. These are identified overlaps allowed by signal indications (and the overlap name (e.g., Overlap A, Overlap B, etc.)). For example, in Figure 4 below, Overlap A is a Phase 2 - Phase 3 overlap where the southbound right-turn is active as an overlap in Phase 3.
- ***Information about pedestrian crosswalk movement phases.*** For example, in Figure 4 below, Phase 2 includes the pedestrian crosswalk indication for the north-south movement, and Phase 8 includes the crosswalk indication for the two east-west movements.
- ***Controller phase to signal group assignments***. Relating the signal controller phases and overlaps to signal groups is done by programming in the signal controller and/or RSU and may vary by equipment manufacturer. This information may be included in signal timing plans or design document for the signal controller or may be information that must be obtained by the traffic signal engineer responsible for the signal. The most common signal phase to signal group assignments are as follows:
  - Phases 1-8 are typically assigned to signal group 1-8;
  - Overlaps A, B, C, and D are typically assigned to signal groups 9, 10, 11, and 12, respectively; and
  - Pedestrian signals in phases 2, 4, 6, and 8 are typically assigned to signal groups 13, 14, 15, and 16, respectively.

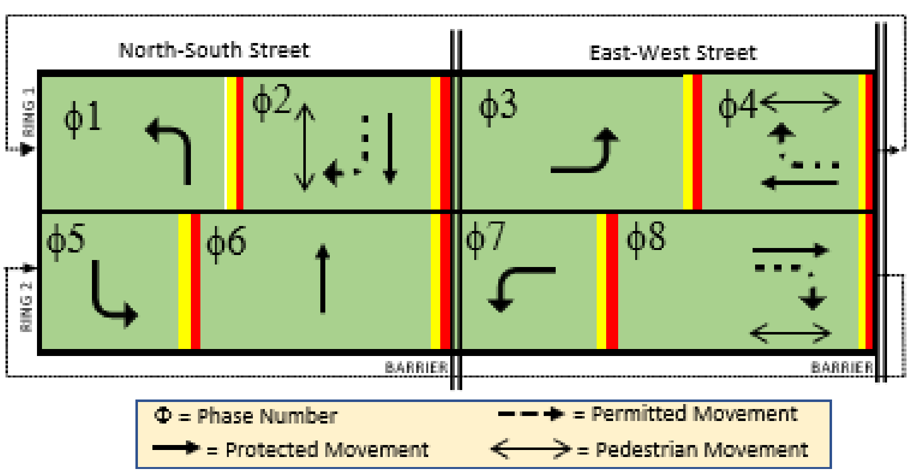


Figure 4: Example signal phase diagram

Source: Athey Creek Consultants

Guidance:

- The Signal Timing Plan for an intersection is the primary source for this information.
- Central signal control software outputs, imagery, or screenshots are alternate sources for this information.
- The MAP creator should seek information about which phases, overlaps, or pedestrian signal indications are assigned to which signal groups by the signal controllers and/or RSU (these may also be referred to as 'channels'). It is important not to assume the typical values identified above are used, but rather to verify the channel numbers with either the signal controller design document or the traffic engineer responsible.

Basis:

- Based on requirements in the CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.1.2.12 Step 1 - Guidance #1.13: Lane Use Variations

When intersections include lanes with usage that varies at different times (e.g., revocable, restricted), the MAP message must provide the information to accompany the SPaT message to convey these variations of use.

Guidance:

- During Step 1, the MAP creator should understand if any lanes in the intersection include lane use variations (e.g., if left-turns are not allowed during peak periods or if travel in a lane is one direction part of the day and another direction during the other) and document the variations of use to support MAP content creation in Step 3.
- During Step 1, the MAP creator should also verify that the SPaT message that is/will be created dynamically for this intersection will broadcast status of all revocable lanes.

Basis:

- Assembling information about lane use variations will support creation in Step 3 – Place Nodes and Create MAP Content.

2.1.2.13 Step 1 - Guidance #1.14: Reference Point

A reference point is needed to allow the node points (described in Step 3) to be identified as offsets from the reference point. This minimizes the file size by avoiding full latitude/longitude numbers for all node points. The reference point must be located inside the intersection defined by the MAP message. The latitude, longitude, and elevation description of the reference point is used to determine the same values of all node points that are defined as offsets from the reference point. In addition to a reference point, a verified point marker is a key element for defining detailed locations of node points and is explained in Guidance #2.1.

Guidance:

- During Step 1, consider using a verified point marker (i.e., a point with a known latitude/longitude and that is visible from any aerial mapping solution) to serve as an "anchor" by which the reference point that is inside the intersection can be determined and used when creating the MAP message. Verified Point markers are further defined in Step 2.
- The reference point for the intersection can be determined by adding a known latitude and longitude offset to the verified point marker to determine the reference point. It is not critical that this be the center point of the intersection, just that the latitude and longitude be known and that the point is inside the intersection.
- Identify one or more landmarks near the intersection (e.g., a corner of signal controller cabinet, a light pole, etc.) that may already have been surveyed in as a known location. If none are found, arrange for an object near the intersection (that is visible from aerial maps) to be surveyed. More details on the verified point marker can be found in Step 2.

Basis:

- The known location of the verified point marker will help minimize errors caused by aerial mapping solutions when selecting node points or placing lanes and crosswalks.

2.1.2.14 Step 1 - Guidance #1.15: Computed Lanes

The SAE J2735 MAP message can specify lane geometries lane by lane, or as a set of computed lanes. Computed lanes may be appropriate if an intersection has lanes that are similar enough that the nodes of one lane can be geometrically transformed to represent additional lanes. See Figure 5 as an example of three parallel similar lanes that may be suitable for computed lanes. The transformations to a specific reference lane are used to define a set of lane(s) as a means of reducing the total MAP message size. Computed lanes are challenging to specify and cannot be used unless there are only translation, scaling, and rotation differences among the lane geometries.

Figure 5: Yellow line overlayed on three straight parallel ingress lanes that match criteria for computed lanes
Map source: Google Maps, Drawing source: Athey Creek Consultants

Guidance:

- The MAP creator should determine in Step 1 whether they are going to use computed lanes or lane-by-lane specifications. The map creation tool(s) used by the MAP creator may assist in this determination.
- Computed lanes should be considered if it will reduce the MAP message file size and if a reduction in the MAP message file size is needed. Computed lanes have the most benefit if there are long,

straight ingress or egress lanes with a minimum of two (preferably three) lanes in each approach that have similar geometries that can be computed. For example, a lane that splits into a through lane and a left-turn lane cannot be computed to represent a through lane (with no turn split).

- A lane is selected to serve as the reference lane. This reference lane should be the lane with the least number of external influences (e.g., parking allowed or uncertainty over the lane markings). Typically, the reference lane will be the left-most through lane as the right lane is typically the curb lane and may have parking.
- The centerline of the reference lane (i.e., line formed by the connecting the node points) will serve as the basis for offsets (computed lanes will have offsets from the reference lane center line) and rotation (i.e., computed lanes will be rotated from the centerline of the reference lane.
- Transformation values to be specified include translation (x and y offsets from the original lane), scaling (expanding or contracting the lane width values), and rotation (path rotation for the entire lane). The rotational transformation values are unsigned units of 0.0125 degrees from 359.9875 degrees (i.e., integer values from 1 to 28799). A value of 1 would add 0.0125 degrees to 359.9875, yielding 360.0000 degrees, or 0 degrees of rotation from the centerline of the reference lane; a value of 7201 indicates a 90 degree clockwise rotation).
- The X and Y scaling are independently set.
- Transformations are relative to the reference lane's initial point and NOT the MAP reference point.
- Computed lanes inherit lane attributes from the referenced lane.
- Computed lanes are recommended only when the reference lane has a similar shape and identical attributes.
- MAP creation tools should determine computed lanes automatically or enable the user to directly create them.

<u>Basis</u>:

- A decision to use computed lanes should be made as part of Step 1 data gathering rather than being deferred to the Step 3 map data assembly.
- The computed lanes data needs are described in SAE J2735.

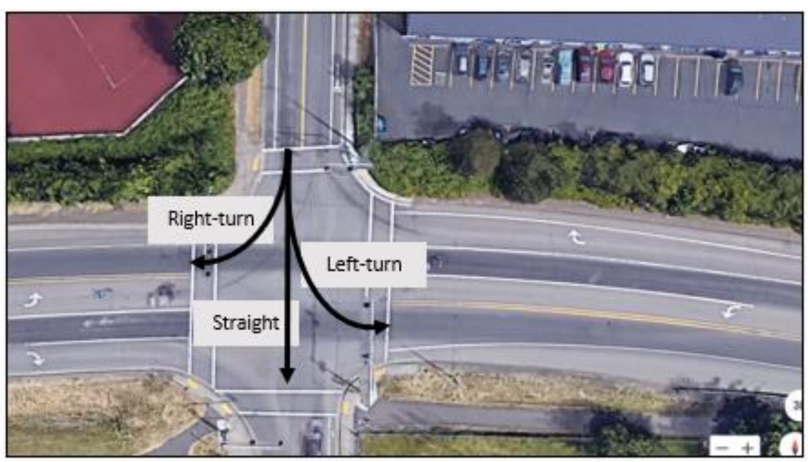


Figure 6: Example illustration of the allowed maneuvers for a southbound ingress lane

Map source: Google Earth, Drawing source: Athey Creek Consultants

2.1.2.15 Step 1 - Guidance #1.16: Allowed Lane Maneuvers

In Step 3 – Place Nodes and Create MAP Content, the MAP creator will need to identify and define all allowed maneuvers for each lane. During Step 1, the MAP creator should assemble information about the maneuvers allowed at the end of each lane (for ingress lanes, this is the stop line; for egress lanes, this is the furthest downstream node). Information gathered in this step will ensure that the actions in Step 3 create a comprehensive list of maneuvers.

Note that the identification of all possible maneuvers for each lane is a different activity than assigning a specific maneuver for each connection (as described in Step 1.9 Connections Between Motor Vehicle Lanes). As an example, the identification of all possible maneuvers may be used by in-vehicle applications to advise drivers of what movements are possible (e.g., right turn on red), whereas the See Figure 6.

Guidance:

- During Step 1, the MAP creator should identify all possible maneuvers for each lane. For example:
  - Verify if U-turns are allowed from any left-turn or through lanes.
  - Verify when right turns are allowed from rightmost lanes or through lanes.

Basis:

- SAE J2735 description

2.1.2.16 Step 1 - Guidance #1.17: Geodetic Reference Systems

MAP creators in Step 2 will be selecting and determining the location of a verified point marker for each map. Each such location is expressed as a global latitude, longitude, and elevation position relative to a specific geodetic frame of reference.

Geographic positions in the U.S. are generally determined using the U.S.'s Global Positioning System (GPS) implementation of a global navigation satellite system (GNSS). Positions determined from GPS are typically expressed using the World Geodetic System (WGS) 84 standard coordinate frame of reference. SAE J2735 further specifies that position data in its messages are to be expressed using WGS 84 coordinates.

Geodetic reference systems other than WGS 84 are frequently used for surveying and associated map locations. In particular, the U.S. National Geodetic Survey uses the North American Datum of 1983 (NAD 83). As another example, the Federal Communications Commission (FCC) license application process for roadside unit (RSU) licensing requires coordinates of the RSU reported in NAD 83. This should not be confused with the SAE J2735 requirement to use WGS 84 as the standard coordinate frame of reference.

It is important to ensure that either 1) the tools used to determine the location of the verified point marker are using the WGS 84 standard, or 2) that the location coordinates are transformed from the source system to WGS 84 for use in MAP messages.

Guidance:

- The MAP creator should identify the geodetic reference system used for determining the location of the verified point marker.

- If the reference system is not WGS 84, the MAP creator needs to transform the coordinates from the source reference system to the WGS 84 frame of reference.
- The MAP creator should then confirm that the coordinates for the verified point marker are recorded using the WGS 84 standard coordinate frame of reference.

Basis:

- SAE J2735 specifications

2.2 Step 2 - Determine Verified Point Marker

Step 2:
Determine Verified Point Marker

A verified point marker is identified in Step 2. The verified point marker is not a data element in the MAP message, but rather is a resource to help increase the accuracy of node points selected using aerial view MAP creation tools. A verified point markers is typically an object that has a fixed location, such as a light pole or a corner of a traffic cabinet at an intersection. Ideally, an accurate and precise location of this marker will be known through a field survey. Similarly, as built or intersection designs may include a verified point marker, but it is likely that a field survey will be required to determine the exact location of this marker. The location of this fixed object is then used to minimize position errors when utilizing MAP creation tools in later steps. Note that the intersection reference point that will be set in Step 3 (Place Nodes and Create MAP Content) and the verified point marker are not the same point.

2.2.1 Objective

If a map-based human interaction tool is used in Step 3 to identify locations of nodes, the underlying maps in the tool will likely have location-related inaccuracies. The objective of this step is to improve location accuracy of the node points by identifying a verified point marker.

If the distance and direction that the mapping solution differs from the true latitude and longitude coordinate can be understood (displacement distance and direction), these displacement values can be used to adjust the node points selected in the tool.

2.2.2 Step 2 Guidance

This section includes guidance for determining the verified point marker as shown in Table 5 below.

Table 5: Step 2 – Determine Verified Point Marker: Guidance List

Step 2	Guidance #2.1	Selection of a Verified Point Marker
	Guidance #2.2	Precision of the Verified Point Marker Coordinates
	Guidance #2.3	Determination and Implementation of Displacement Distance/Direction

The following subsections provide guidance in determining the verified point marker.

2.2.2.1 Step 2 - Guidance #2.1: Selection of a Verified Point Marker

Selecting an appropriate verified point marker will help ensure that all position adjustments are as accurate as possible.

Guidance:

- The verified point marker must be a stationary object.
- The object needs to be visible from the aerial view of the mapping tool with no obstructions such as tree foliage.
- There needs to be a distinguishable element to the object that can be used as the survey point and location within the aerial view of the mapping tool (e.g., the southwest corner of the traffic signal cabinet versus simply identifying the entire cabinet).

- Viewing an aerial view of the intersection in the map tool prior to selecting a verified point marker may be helpful for identifying potential fixed objects that are unobstructed, not in shadows or out of focus, and easily identified. See Figure 7.

Figure 7: Example of a candidate verified point marker
Map source: Google Earth, Drawing source: Athey Creek Consultants

- Noted practices include:
  - Objects that were previously surveyed and are visible in aerial views are optimal choices for visible point markers.
  - The upright pole for the mast arm closest to the traffic controller cabinet is sometimes selected, assuming that it is easily viewed in the aerial photo. However, aerial images are largely taken from planes with GPS systems onboard and almost always have varying levels of image perspective for objects with height. To eliminate the issue of image perspective, objects that are very low to the ground should be used, such as the northwest corner of the base of a signal cabinet, or the corner of a permanent bench.

Basis:

- Verified point markers are needed to understand and correct the deviation between known positions and position data gathered from various approaches (e.g., aerial views).
- Guidelines reflect practical uses and needs for verified point markers.

2.2.2.2 Step 2 - Guidance #2.2: Precision of the Verified Point Marker Coordinates

Successful use of a verified point marker requires compatible levels of precision between the field approach to determine the position and any values returned by mapping tools.

Guidance:

- The verified point marker shall be described by latitude and longitude values with a minimum of six significant decimal places for better than 0.011132-meter accuracy. (SPaT V2I Interface for Red Light Violation Warning System Requirements Specification)

Basis:

- SAE J2735 calls for expressing latitude/longitude in 0.1 micro degrees.

2.2.2.3 Step 2 - Guidance #2.3: Determination and Implementation of Displacement Distance/Direction

The value of the verified point marker is in determining and implementing corrections to locations returned from the mapping tool. To accomplish this, the following are needed:

- Correction distance/direction is needed for both the latitude and longitude of the verified point marker. This is done by calculating the N and E offset between the lat/long of the verified point marker as measured in the field survey and the lat/long of the verified point marker as determined on the aerial photo.
- A systematic approach is needed to apply the displacement distance.
- The location of the verified point marker specified with the same datum as used for the aerial imagery. In the case of online maps and OBUs this will be WGS84, however surveys typically use the NAD83 geodetic system.

Guidance:

- The USDOT Tool has a feature that asks users to click the verified point marker on the map. After clicking, the user is asked to enter the latitude/longitude that is known for the verified point marker. The USDOT Tool automatically sets a displacement distance and direction for all points that are selected in the tool for the intersection.
- If a tool is being used that does not allow for the entry of a verified point marker, manual calculations would need to be performed by clicking on a verified point marker within the mapping solution and comparing the latitude/longitude to the known location of the verified point marker. Adjustments should then be applied to each node point.

Basis:

- Definition of verified point marker in the USDOT Tool.

2.3 Step 3 - Place Nodes and Create MAP Content

Step 3: Place Nodes and Create MAP Content

Step 3 assembles data gathered in earlier steps into content for the MAP message.

2.3.1 Objective

The objective of Step 3 is to assemble the data collected in Steps 1 and 2 into the MAP message content. The content assembled can be used for configuration management and validated graphically in Step 4 and is converted into a SAE J2735-compliant MAP message in Step 5. The message content assembled in Step 3 has three types of content:

- Intersection identifiers;
- Intersection lane geometry information; and
- Signal group information associated with each lane.

2.3.2 Overview

This section provides an overview of Step 3 including the approaches to assembling message content, selection and entry of lane node points, and manual assembly of the MAP message.

2.3.2.1 Assembling Message Content

Interest in and need for MAP messages is increasing the number of tools available to assist in their creation. Early connected vehicle application deployments depended on a manual process for developing MAP messages. The manual process required a detailed knowledge of the standard message specifications. Much of that knowledge is built into the automated tools, but they still need complete and accurate data to produce accurate and useful MAP messages.

Guidance in this section is focused on assembling data gathered in prior steps to assure consistency in MAP message content. It is recommended that the gathered data be bundled with consistent identifiers for configuration management.

2.3.2.2 Selection and Entry of Lane Node Points

The selection of lane node points is the core of building the MAP message content. Details about the arrangement of and relationships between lanes and movement through the intersection all depend on geometries as defined by the lane node points.

The raw data from which node point locations are derived may be based on any of several alternative representations of roadways with geodetic references, including:

- Map data from a geographic information system (GIS)
- Aerial/satellite photos with geodetic references
- Maps with photo backgrounds
- As-built design drawings for the intersections, with geodetic references
- Traditional field survey data
- Light detection and ranging (LiDAR) surveys

The application of any one of these data sources in setting node point locations will depend completely on the tool(s) being used to assemble the MAP message. Many of the MAP message tools enable users to select lane centerline node points on maps overlaid on satellite photos. This has the advantage of providing visual clues for appropriate node locations in a geodetic-referenced framework. It is limited, however, to the accuracy of the visual image source and its referencing. The data provided in as-built drawings and design documents may be more accurate, if the MAP message tool is able to ingest those data. LiDAR data shows promise as a basis for automating the generation of MAP messages but requires extensive processing to reduce the LiDAR point clouds and synthesize the node locations. Use of LiDAR surveys thus far appears to be limited to proprietary methods and mapping service providers.

2.3.2.3 Manual Assembly of the MAP Message

Some of the early MAP message developments did not have access to a dedicated graphical tool for selecting node locations. The data were derived from map tools with photo backgrounds for each node point. As demonstrated in those cases, it is possible to assemble the data into a form that can be then read and translated into the UPER-encoded SAE J2735-compliant MAP message. The format of the input file in that case would be specified by the tool or methods being used to perform the encoding. For example, the data could be entered in a human-editable and human-readable JavaScript Object Notation (JSON) format consistent with the USDOT Tool input and output. The JSON file could then be translated into the UPER format using the USDOT Tool.

2.3.2.4 MAP Message Creation Tools for Placing Nodes and Creating MAP Content

Guidance in this document for assembling the MAP message content is not tied to any particular tool that might be used for that purpose. Developers of MAP messages have assembled data using spreadsheets, online maps, custom software, tools produced in Federal projects, commercial tools, and full-scope outsourced services (from field surveys to completed MAP messages). There are, however, some aspects of tool selection that may simplify the process in Step 3 for placing nodes and creating MAP content.

- Fundamentally, any tool used to assemble MAP message content must eventually be able to produce an UPER-encoded SAE J2735-compliant MAP message.
- The tool must address all of the required elements of an SAE J2735-compliant MAP message.
- The tool should provide a human-readable intermediate-format output (e.g., JSON or NMAP) for quality control and configuration management purposes.
- The tool should be able to render the intermediate format message content directly to the UPER-encoded format for configuration management purposes.
- The tool may be able to manage MAP message revision numbering.
- The tool may be able to import and render MAP message content from a GIS.
- The tool may provide a graphical means of placing node points for lanes, perhaps using tools overlaid on a background aerial or satellite image of the roadway.
- The tool may be able to compute the node point offsets.
- The tool may be able to capture lane widths for each lane.
- The tool may provide a graphical means of indicating connections between ingress and egress lanes.

- The tool may enable the user to specify or upload the background image.
- The tool may enable the user to specify time-based variations of lane use (e.g., reversible lanes, turn restrictions, and parking restrictions) and create separate lanes for each use.
- The tool may be able to minimize the resulting MAP message size through:
    - Optimization of the node point offset representations.
    - Automating generation of curve node points from the start, mid, and end points.
    - Automatically creating computed lanes.

2.3.3 Step 3 Guidance

MAP Creators are encouraged to review the guidance listed in Table 6 below as appropriate for their intersection when developing MAP messages for placing nodes and creating MAP content.

Table 6: Step 3 – Place Nodes and Create MAP Content: Guidance List

Step 3 – Place Nodes and Create MAP Content	**Intersection Descriptors**	
	Guidance #3.1	Incrementing MAP Message Revision Counter
	Guidance #3.2	Intersection Reference ID and Road Regulator ID
	Guidance #3.3	Incrementing Intersection Geometry Revision Counter
	Guidance #3.4	Reference Point
	Intersection Lane Geometry	
	Guidance #3.5	Lane Width
	Guidance #3.6	Speed Limits
	Guidance #3.7	Lane ID
	Guidance #3.8	Node Point Geometry and Attributes
	Guidance #3.9	Node Point Accuracy
	Guidance #3.10	Node Point Precision
	Guidance #3.11	First Node Point – Ingress Lane
	Guidance #3.12	First Node Point – Egress Lane
	Guidance #3.13	Length of Ingress Lane
	Guidance #3.14	Length of Egress Lane
	Guidance #3.15	Node Spacing in Vertical Curves
	Guidance #3.16	Node Spacing in Horizontal Curves
	Guidance #3.17	Node Placement for Through Lane Splits into Through Lane and Turn Lane
	Guidance #3.18	Non-Signalized Intersections
	Guidance #3.19	Flyover Lanes
	Guidance #3.20	Parking Lanes
	Guidance #3.21	Node Offsets
	Guidance #3.22	Crosswalks
	Guidance #3.23	Turning Lanes: Channelization and Traffic Islands
	Guidance #3.24	Turning Lanes: Egress Merge Lanes
	Guidance #3.25	Turning Lanes: Mid-Block Left-Turn Lanes
	Guidance #3.26	Turning Lanes: Two-Way Left-Turn Lanes
	Lane Use Descriptions	

The following subsections provide guidance for placing nodes and creating MAP content.

2.3.3.1 Intersection Descriptors

There are a number of intersection descriptors described in this section: intersection reference ID and road regulator, incrementing MAP message revision counter, increment geometry revision numbers, and reference point.

2.3.3.1.1 Step 3 - Guidance #3.1: Incrementing MAP Message Revision Counter

Each MAP message includes a message revision number. OBUs will compare the revision number to stored MAP messages to determine if the current message has been updated since it was last received.

Guidance:

- The revision should be incremented by one when the content of the MAP message has changed.
- The range of this value is 0 to 127. After reaching 127, the revision number restarts at 0.
- A MAP message may contain descriptions for multiple intersections and/or road segments, which have independent, intersection revision counters for each defined intersection in the message, as described in Guidance #3.3, below.
- Saving a MAP message in the USDOT Tool requires the input of a revision number.

Basis:

- SAE J2735 defines this data element as an integer, value 0 to 127.

2.3.3.1.2 Step 3 - Guidance #3.2: Intersection Reference ID and Road Regulator ID

The intersection reference ID (combined road regulator ID and intersection ID) is how OBUs ensure that they are processing the MAP and SPaT message for the same intersection. Guidance in Step 1 – Assemble

Data described activities to determine the numbering approach used for both IDs. During Step 3, the reference identifiers are added to the MAP content.

Guidance:

- Ensure that the intersection ID and road regulator ID are populated for each intersection and that the IDs in the MAP message match that of the SPaT message.

Basis:

- As per the SAE J2735 standard.

2.3.3.1.3 Step 3 - Guidance #3.3: Incrementing Intersection Geometry Revision Counter

Each MAP message includes detail for at least one and possibly more intersections or road segments. Intersection geometry revision counters identify the current version of the geometry for each intersection and/or road segments within the MAP message.

OBUs will compare revision numbers of MAP messages and intersection geometries to stored messages to determine if the received MAP message has been updated since it was last received.

Guidance:

- When an intersection geometry description is updated, the revision number for that geometry should be updated.
- The revision number of the MAP message containing the updated geometry should be incremented as well.
- If the MAP message contains only one intersection, the message counter and the intersection counter would be the same value.
- If the only change is an update to the time stamp, do not increment the intersection geometry revision counter or the MAP message revision counter.
- The range of this value is 0 to 127. After reaching 127, the revision number restarts at 0.

Basis:

- SAE J2735 defines this data element as an integer, value 0 to 127.

2.3.3.1.4 Step 3 - Guidance #3.4: Reference Point

Each MAP message requires a reference point. The reference point can be any point in proximity to the intersection(s) defined by the MAP message. This guidance suggests that the reference point always be located inside the intersection, but it is not important that it be at the center of the intersection. The latitude, longitude, and elevation of the reference point are used to compute offsets for the lane node points. See Figure 8.

Keep in mind that the intersection reference point is not a node point. It is not a point that a vehicle will travel over and need to match its location to. Rather, once the lat/long/elevation of the first node point of each lane is determined, those node points will be coded for brevity in the MAP message as the horizontal, vertical, and elevation difference from the reference point. The fact that the MAP message includes the combination of the lat/long/elevation of one reference point and the offsets from that point for multiple node points is a way of enabling the OBU to determine the lat/long/elevation of each node point without having to communicate the payload that would be required to communicate the full lat/long/elevation for every node point.

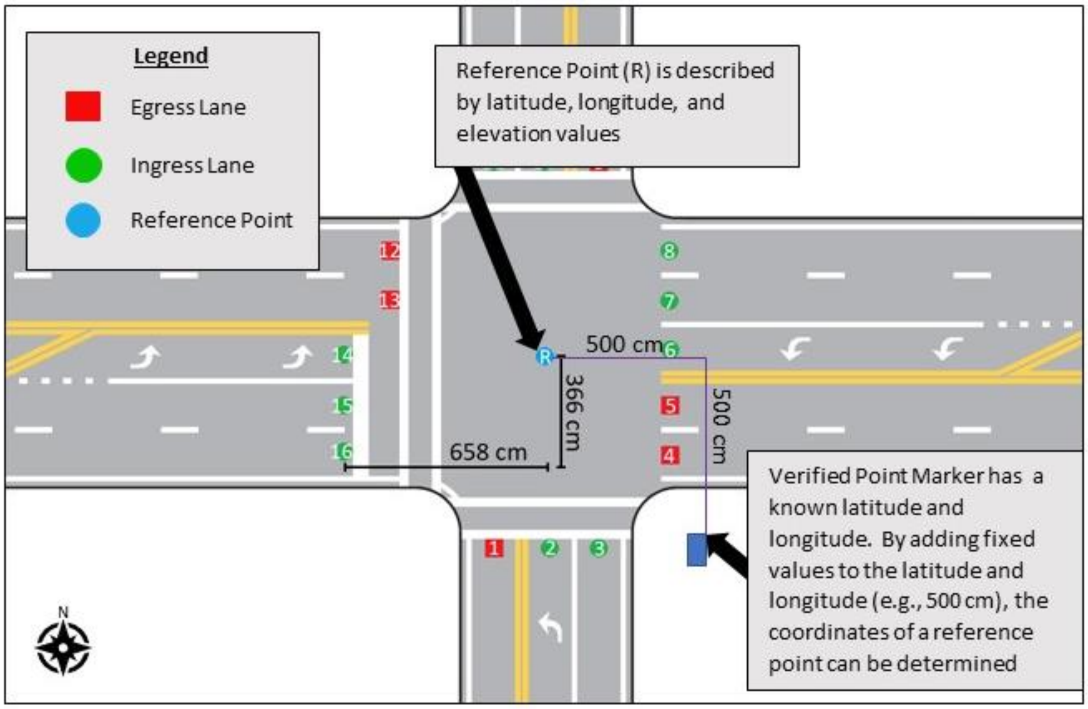


Figure 8: Reference point
Source: Synesis Partners

Guidance:

- Since the initial node of each lane of the intersection will be defined as an offset from a reference point, placing a reference point (i.e., latitude, longitude, and elevation value of a location) inside the intersection minimizes the distance offset to each lane's initial node.
- Select the location of a reference point that is inside the intersection.
    - This can be done by surveying a point inside the intersection to determine the lat/long and elevation of the reference point. If a surveyed point is used, this can be entered into the MAP Creation Tool.
    - If using a MAP Creation Tool and a physical survey of a reference point inside the intersection is not possible, solely clicking on a location using the aerial mapping resource in the MAP Creation Tool is unlikely to return an accurate value of lat/long and elevation. For this reason, a verified point marker (as described in Step 2.1) can be used to understand the deviation between known positions and the position delivered using aerial views. The MAP Creation tool allows for users to enter the surveyed position of the

verified point marker and performs the correction to the position where the user clicked to select the reference point.

- If not using a MAP Creation Tool and is is not possible to physically survey a reference point, record the measured geo-coordinates of the verified point marker and apply a value for both the horizontal and vertical distances from the verified point marker a location inside the intersection (i.e., the horizontal and vertical distance selected will determine where your reference point is) to calculate the lat/long of the reference point.

- The recommendation is to use the verified point marker (i.e., a point with a known latitude/longitude and that is visible from any aerial mapping solution) identified and located in Step 2 to determine the reference point. This can be done by adding an arbitrary latitude and longitude to the verified point marker to calculate the coordinates of the reference point that is inside the intersection. Note: If using offsets from the Verified Point Marker, this will not calculate the change in elevation between the Verified Point Marker and the calculated reference point. Placing a reference point inside the intersection minimizes the distance offset to each lane's initial node, but there is unlikely to be a verifiable landmark at that location. In either case, be sure to record the measured geo-coordinates of the verified position and the horizontal and vertical distance between the verified position and reference point.

Basis:

- The known location of the verified point marker will help minimize errors caused by aerial mapping solutions when selecting node points or placing lanes and crosswalks.

2.3.3.2 Intersection Lane Geometry

This section includes guidance related to intersection lane geometry.

2.3.3.2.1 Step 3 - Guidance #3.5: Lane Width

The lane width is an optional field in the MAP message and is used as a reference lane width for reporting the lane width at any node approaching or leaving the intersection. Each node may include a "delta" value defining the change in the width at that node from the reference lane width defined for the intersection. For example, an intersection with similar and regular lanes widths may include just one value (300 cm), while another intersection having a wide variation in the lane widths between approaches would reduce the lane width (e.g., -50 cm) for lanes that are narrower than the standard width. Any deltas from the reference lane width are entered as offsets from the prior node. For example, in a lane that is 50 cm narrower than the reference lane width, the first node contains the delta value of -50 cm. Subsequent nodes do not require additional delta values unless they differ in width from the prior node. The example intersection (illustrated in Figure 9) contains a variety of lane widths. Westbound ingress lanes consist of a bike lane, two through lanes and one left-turn lane. Eastbound egress lanes consist of two through lanes and one bike lane. The typical lane width that would be chosen as the reference lane width would be 12 feet (366 cm). Three of the through lanes do not need a lane width delta as they match the reference lane width. The westbound left-turn lane and one eastbound through lane need a lane width delta of +2 feet (61 cm), while the westbound bike lane would have a lane width delta of - 2 feet (-61cm), and the eastbound bike lane would have a lane width delta of -6 feet (-183 cm). The lane width adjustments need only occur for the initial node of the subject lane since the lane width remains consistent. See Figure 9.

Figure 9: Lane width

Map source: Google Maps, Drawing Source: Synesis Partners

Guidance:

- It is strongly recommended that the lane width value source should be based on IOO verified sources for the lane width (e.g., design document, as-built, surveys, LiDAR-recorded data, etc.).
- If budgets are constrained, lane width value may be approximated using an online mapping resource if this solution is acceptable for applications, but this is not recommended as a primary or default solution.
- IOOs should only enter node point lane width deviations if verified sources are available.
- Values for median widths are not required in the MAP message.
- Use the most common lane width for the reference lane width.

Basis:

- Current online mapping and digital imagery solutions in MAP creation tools that require users to click on two lane lines to compute a lane width value are likely to return inaccurate lane widths that do not meet the minimum requirements defined by CTI 4501 v01.01.
- Calculating and determining an accurate lane width at the location of each node is not practicable for all IOOs.

2.3.3.2.2 Step 3 – Guidance #3.6: Speed Limits

The speed limit is a required data element by this Guidance for the MAP message. Speed limit is a required element in CTI 4501 v01.01, but is an optional field in SAE J2735 for the MAP message. The regulatory speed limit (also referred to as the posted speed limit or statutory speed limit) may support on-board applications such as RLVW to calculate stopping distance or to determine braking assistance support. Rather than specify the speed limit for each individual lane, the regulatory speed limit that is entered for the first lane is assumed to be the same regulatory speed limit for subsequent lane until a new value is inserted (i.e., each lane within an approach generally has the same speed limit, however the approach lanes for intersecting streets may have a lower or higher speed limit). Additionally, if speed limits decrease or increase within a lane either upstream or downstream of the intersection, an additional node point should be entered where the speed change occurs, such that the new speed limit will be identified for that an all subsequent nodes in the lane. Note that not all MAP Creation Tools are capable of including speed limit data, such that this data element may need to be added manually.

Guidance:

- Include regulatory (i.e., posted or statutory) speed limit information as part of the MAP message.
- Enter the speed limit value for the first lane and any subsequent instance when a speed limit value for the lane differs from the previous lane (i.e., the speed limit value for the first lane is assumed to be the speed limit for subsequent lanes until a new speed limit value is provided). When an approach has a different speed limit from the speed limit of the prior lane, enter the speed limit value at the node for the first lane where the speed limit is different.
- For speed limits that change within a lane, create a node point at the location where the speed changes and indicate the new speed limit.

Basis:

- The posted or statutory speed limit is a required data element in CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.3.3.2.3 Step 3 - Guidance #3.7: Lane ID

Each lane at a connected signalized intersection must have an identifier that is unique for the intersection.

Guidance:

- Lane identifiers must be whole numerical values between 1 and 254, inclusive.
- Selection of lane numbers - There are no pre-defined patterns for creating lane identifiers, but each agency is recommended to follow a consistent pattern for all intersections (e.g., start with the curbside, west-bound ingress lane, and number sequentially in a clockwise order).
- Lane IDs are required for all lanes, including crosswalks and sidewalk lanes.

Basis:

- SAE J2735 requires 1-byte integer values.
- SAE J2735 identifies that the value 0 shall be used when the lane ID is not available or not known.
- SAE J2735 identifies that the value 255 is reserved for future use.

2.3.3.2.4 Step 3 - Guidance #3.8: Node Point Geometry and Attributes

The MAP message describes the geometry of the center of each lane by identifying node points that define line segments between the nodes. As a minimum, at least two node points are identified for each lane. Node points are represented in SAE J2735 as offsets. First node points of each lane are offsets of the reference point. Subsequent node points of each lane are offsets from the previous point.

The most recognized attributes of node points are latitude, longitude, and elevation, or, in the case of offset points, the north offset and east offset from the reference point or previous node. However, attributes of node points are also used to describe changes in lane width and speed limit from the reference lane width and reference speed limits defined for the intersections. Additional details about lane widths are included in Guidance #3.5: Lane Widths and additional information about reference speed limits are included in Guidance #1.5. The most common speed limit type used to describe the speed limit attribute is "maximum speed". However, other types, such as "Maximum Speed in School Zone When Children are Present" can be used to indicate additional speed limits. Since the only method for indicating a change in speed limit from the reference speed limit is by defining attributes of a node point, additional nodes would be needed to indicate the start and end of these areas where additional speed limits apply. Additional details of the speed limit attribute for node points can be found in Scenario #1 in Section 3.0 of this document.

Guidance:

- Each node point should be defined by latitude, longitude, and elevation, or offset values.
- Node points also include descriptions of lane width and speed limit, when changes from the reference values are appropriate for the node.
- The maximum offset distance between nodes is 327 meters.
- Define the latitude, longitude, and elevation of node points using one of the following processes:
    - An automated data collection process (e.g., LiDAR),
    - A manual interactive tool (e.g., the USDOT MAP Creation Tool, GIS extract tool, other vendor provided tools, etc.),
    - Intersection as-builts, or
    - By conducting a field survey of the intersection. Specifically:
        - For each ingress lane, conduct a field survey to identify the coordinates of the location where the center of each lane edge line and the upstream edge of the stop line of that lane intersect. Using these points, determine the coordinates of the lane center point at the stop line for each ingress lane. Record this as the first node point of the ingress lane.
        - For each egress lane, conduct a field survey to identify the coordinates of the location where the center of each lane edge line intersects with the downstream edge of the crosswalk or other indicator of the edge of the intersection. Using these points, determine the coordinates of the lane center point for the first node point of the egress lane.

    - For each lane, conduct a field survey to identify the coordinates of the location of at least one additional node point upstream of the first node point by determining the latitude/longitude/elevation of the lane edge centerlines and calculating the coordinates of the center of the lane.
    - In ingress or egress approaches with a horizontal curve, survey additional points to determine the coordinates of additional centerline lane node points, using Guidance #3.16 to determine the number of additional nodes.
- Only enter speed limit values for those node points that either start or end a segment of road where the speed limit differs from the reference speed limit defined for the intersection (or differs from the adjacent node point).

Basis:

- This process replicates the testing and validation recommended in the CV PFS Connected Intersections Guidance Document.
- The ability for on-board applications to determine the correct lane is dependent on the node points being in the center of each lane.
- Latitude and longitude are required by on-board applications to identify the nearest node point(s).
- Elevation is required by on-board applications to determine the slope or grade of the approach to the intersection.

2.3.3.2.5 Step 3 - Guidance #3.9: Node Point Accuracy

Accuracy of at least 0.2 meters for each node point has been identified as needed to enable OBUs to properly identify the lane in which the vehicle is traveling. This accuracy is required for latitude, longitude, and elevation values. IOOs developing MAP messages will benefit from consistent, reproducible, practical approaches to ensuring node point accuracy. See Figure 10.

If the process used to identify node point geometry in Guidance #3.8 was to conduct a field survey to determine the coordinates of the node point, this step is optional.

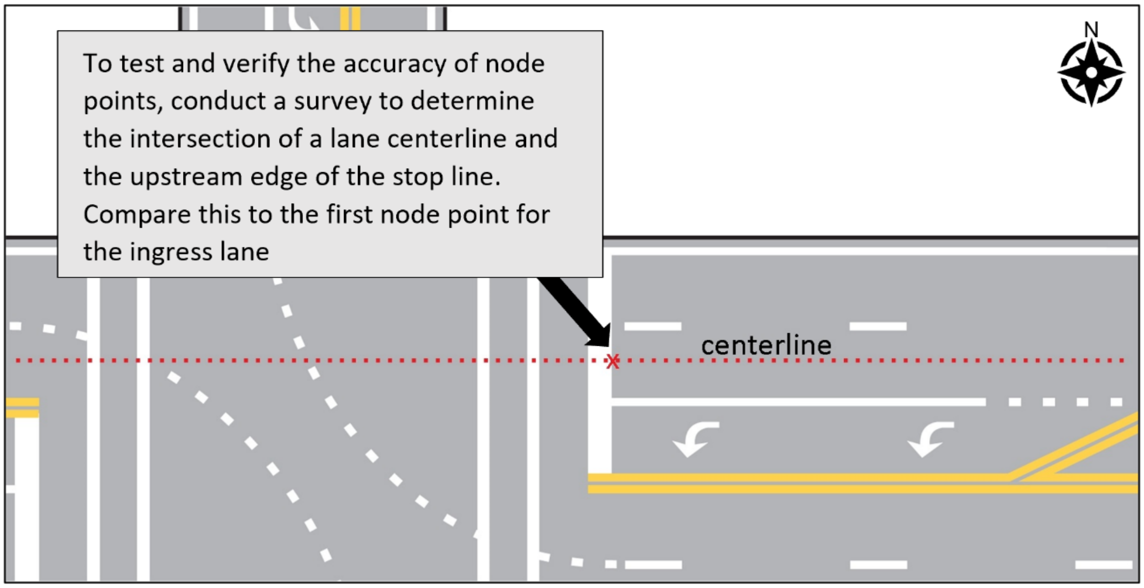


Figure 10: Node Point Accuracy
Source: Synesis Partners

Guidance:

- Use your agency process for conducting a field survey to measure the_latitude, longitude, and elevation of the following:
    - The point at which the center of lane edge lines for each ingress lane intersects 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 coordinate values for this point 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, collect additional measurements of the lane edge lines to determine an accurate representation of the centerline nodes.

Basis:

- This process replicates the testing and validation recommended in the CV PFS Connected Intersections Guidance Document.

- The decision to use the value of 0.2 meters is derived from the CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.3.3.2.6 Step 3 - Guidance #3.10: Node Point Precision

The number of significant decimal places in values for latitude and longitude impact the interpretation of the location description. Too few significant decimal places are interpreted as values of zero and change the locations.

Guidance:

- The latitude and longitude values describing node points shall include a minimum of six significant decimal places for better than 0.011132-meter accuracy.
- Offset points are not expressed in degrees.

Basis:

- SAE J2735 calls for expressing latitude and longitude in 0.1 micro degrees.

2.3.3.2.7 Step 3 - Guidance #3.11: First Node Point – Ingress Lane

As on-board applications receive and interpret node points describing an ingress lane, it is important to have a clear understanding of which node point is at the stop line and that the position can be determined consistently. See Figure 11.

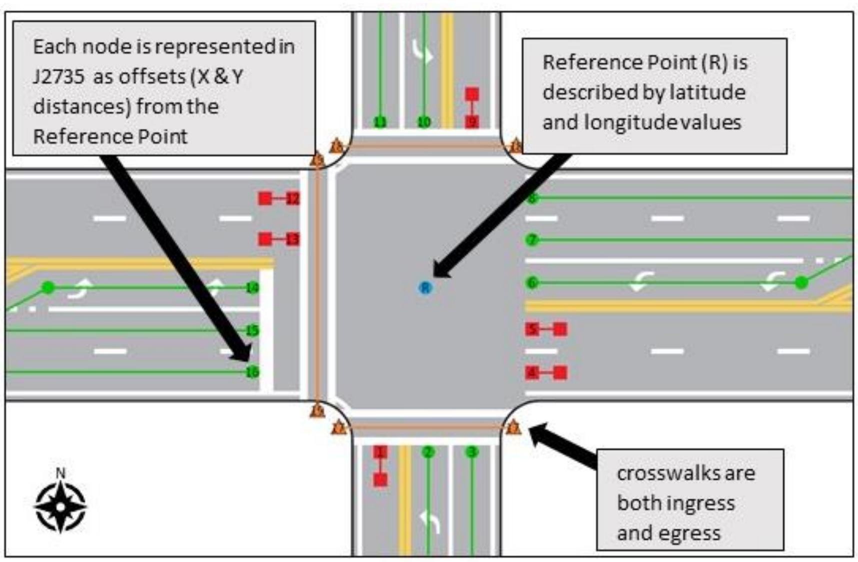


Figure 11: Ingress and egress lane numbering and first node points
Source: Synesis Partners

Guidance:

- When creating a list of node points for ingress lanes, the first node point should be the node point located at the stop line.

- The first node point should be located at the upstream edge of the stop line (i.e., point where the vehicle would cross into the stop line).
- In the absence of a stop line, the first node point should be placed on the upstream edge of a crosswalk.
- In the absence of a stop line and crosswalk, the first node point should be placed, using engineering judgement, at the nearest point at the upstream edge of the intersection.

Basis:

- SAE J2735 indicates that the first node is the closest to the reference point, when describing a path (typically the stop line).
- Because on-board applications (e.g., the RLVW application) may use the first node point to determine the vehicle distance to the stop line, it is important that this position be the upstream/start of the stop line (not middle or downstream edge of the painted line).

2.3.3.2.8 Step 3 - Guidance #3.12: First Node Point – Egress Lane

It is important for interpretation of egress lane geometry to have consistent practice in placement of the first node. See Figure 11 above.

Guidance:

- When creating a list of node points for egress lanes, the first node point should be the node point closest to the intersection.
- When there is a crosswalk, the first egress point should be located at the downstream line/edge of the crosswalk striping (i.e., point where the vehicle would have cleared any pedestrians in the crosswalk).
- In the absence of a crosswalk, the first egress point should be determined with engineering judgement to represent the point immediately outside the intersection and any path that pedestrians might use to cross the intersection, whether striped or not. For example, curbs or cross lanes of travel could be used as references to determine the boundary of the intersection.
- In situations where a lane is defined as both an ingress and egress lane using revocable lanes, the first node point of the ingress lane should follow guidance for the first node point of ingress lanes and the first node point of the egress lane should follow guidance for the first node point of egress lanes.
- should be assigned based on the stop line (i.e., the node point location of the Ingress lane).

Basis:

- SAE J2735 indicates that the first node is the closest to the reference point, typically chosen as the beginning point of a roadway segment when describing a path. Note: if a verified marker point outside the intersection (e.g., signal cabinet) is selected as the reference point, the first node will not always be closest to the reference point).
- Because on-board applications may use the first node point of the egress lane to determine the vehicle distance to clear the intersection (for example, with the RLVW application), it is important

that this position be the downstream/end of the crosswalk striping (not middle or upstream edge of the painted line).

2.3.3.2.9 Step 3 - Guidance #3.13: Length of Ingress Lane

The location of the final node point of an ingress lane will define the length of the ingress lane. In general, longer ingress lanes afford more time and distance for in-vehicle applications to determine the lane of travel and perform actions prior to the intersection. As soon as a vehicle is within the broadcast range of the intersection's RSU, the in-vehicle applications will receive the MAP message and may begin determining the lane of travel based on the vehicle position and the position of ingress lane nodes. Therefore, ingress lanes that extend to the boundary of the broadcast range of the RSU (nominally 300 meters) would provide in-vehicle applications with the maximum time to process and use the MAP message. However, there are some factors that may limit the length of ingress lanes:

- ***Node accuracy and message size.*** As noted in Guidance #3.16: Node Spacing in Horizontal Curves, node accuracy is critical, and ingress lanes with horizontal curves require additional node points to ensure accuracy. As a result, the required number of node points for ingress lanes with horizontal curves, and therefore size of the MAP message, may limit the extent of the ingress lane.
- ***Upstream signalized intersections.*** When there are nearby upstream signalized intersections to the connected intersection, MAP creators face a dilemma of either extending the ingress lane into and beyond the upstream intersection or stopping the ingress lane short of the upstream connected intersection and therefore potentially short of the desired length to support applications.
- ***Upstream non-signalized intersections***. Eventually, there will be a need for MAP messages describing all intersections, whether signalized or not. The dilemma of whether to extend ingress lanes into and beyond upstream non-signalized intersections is a factor in determining ingress lane length. Upstream ingress lanes are not allowed to extend into upstream signalized intersections but may extend into upstream non-signalized intersections. If ingress lanes extend through upstream non-signalized intersections today, these MAP messages will need to be reworked if the upstream intersection becomes signalized in the future.

IOOs deploying connected intersections may not be aware of all the potential current or future applications for the SPaT/MAP broadcasts. Some onboard applications may rely on determining the approach lanes earlier than others. MAP message creators therefore need guidance on determining the length of the ingress lanes. See Figure 12.

<u>Guidance</u>:

- Consider extending ingress lanes for the distance of the broadcast range of the RSU, (nominally 300 meters) while keeping in mind the accuracy needs of node points, the file size limitations of MAP messages, and the proximity of upstream intersections.
- If possible, the minimum length of the ingress lanes should provide at least 10 seconds of vehicle travel in the ingress lane before the stop line. This length may be computed by multiplying the speed in mph by 4.469 to receive distance in meters (for example: 25 mph = ingress of 112 meter;

50 mph = ingress of 223 meters). The recommendation is to use the 85th percentile speed in the calculation or (if 85th percentile speed is not available to use the speed limit plus 7 mph.)

- It is acceptable for ingress lanes to extend and overlap the egress lanes of upstream intersections.
- The nodes defining the ingress lane to a connected intersection shall not extend into the intersection conflict area of upstream signalized intersections (i.e., the intersection conflict area is typically bounded by crosswalks or outside lanes of crossing traffic lanes).

Basis:

- The CTI 4501 v01.01, Connected Intersections Implementation Guide states that ingress lanes may NOT extend into the conflict area of an upstream intersection.
- The CTI 4501 v01.01, Connected Intersections Implementation Guide states that whenever possible, the minimum travel time for on-board applications to be effective at warning drivers approaching intersections is 10 seconds after arriving at the ingress lane in the MAP message.
- The CTI 4501 v01.01, Connected Intersections Implementation Guide states that ingress lanes may extend beyond the egress lanes of upstream intersections.

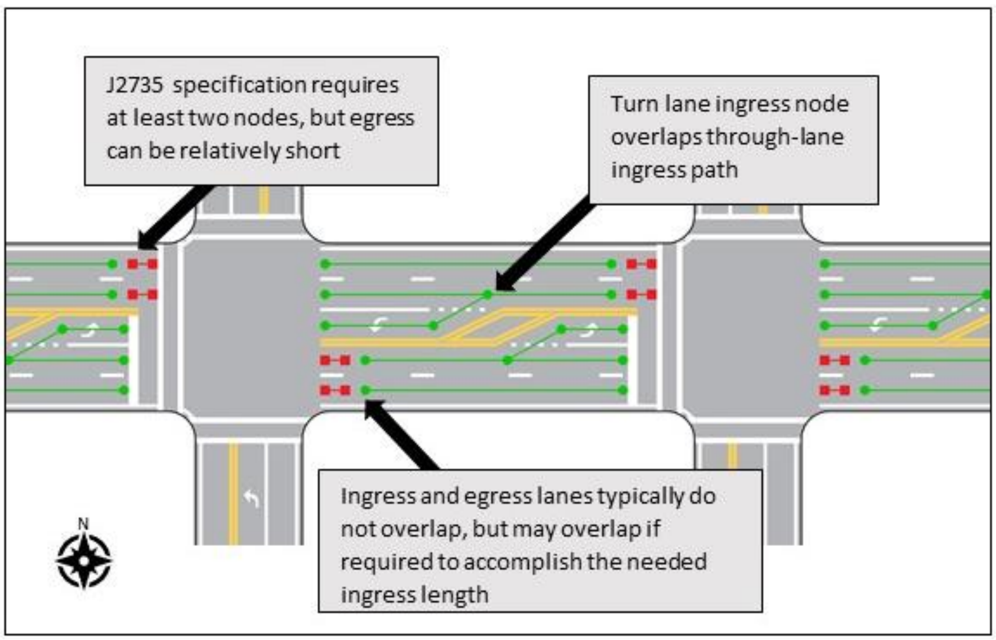


Figure 12: Length of ingress and egress Lane
Source: Synesis Partners

2.3.3.2.10 Step 3 - Guidance #3.14: Length of Egress Lane

Information about egress lanes may be used by on-board applications during the approach, progression through, and clearance of the intersection. Egress lane data may also be needed for some in-vehicle applications. For example, wrong way driving applications may use the egress lane to determine if a vehicle is traveling against the flow of traffic towards the intersection. The egress lane length nonetheless needs to accommodate ingress lane lengths sufficient to enable on-board applications to identify intersection approach lanes as early as possible. See Figure 12 above.

Guidance:

- Egress lanes should always contain at least two node points.
- Egress lanes may overlap the ingress lane of the downstream intersection.
- Whenever possible without overlapping ingress lanes, a minimum egress lane length of 3 meters is recommended.

Basis:

- SAE J2735 requires that all lanes have at last two points.
- At a speed of 60 mph and a nominal BSM rate of 10 Hz, 3 meters would be a minimum egress length to allow IOOs to capture at least one BSM from each vehicle in the egress lane.
- The CTI 4501 v01.01, Connected Intersections Implementation Guide states that ingress lanes may extend beyond the egress lanes of upstream intersections.

2.3.3.2.11 Step 3 - Guidance #3.15: Node Spacing in Vertical Curves

> ! This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

On-board applications such as RLVW may use the slope or grade of the travel lane to calculate stopping distance or to determine braking assistance support. The elevation of the node point can be used to derive the grade of the road. In some locations where vertical curves exist at the ingress or egress, long distances between node points may not adequately represent the slope that the vehicle encounters.

Guidance:

- In situations where there is grade difference on the ingress or egress, node point spacing shall consider the elevation of nodes to ensure that vertical curves are represented.

Basis:

- The elevation difference between two nodes may be minimal while the grade encountered while traveling between the two node points could include a vertical curve, presenting unexpected challenges to braking or accelerating.

2.3.3.2.12 Step 3 - Guidance #3.16: Node Spacing in Horizontal Curves

OBUs process sequential node points to determine and verify their position. Horizontal curves create situations where the tangent to the curve may deviate from the centerline of the lane by distances outside the acceptable error range. See Figure 13.

Figure 13: Node spacing in horizontal curves

Map source: Google Maps, Drawing Source: Synesis Partners

<u>Guidance</u>:

- Node points should be created such that the perpendicular distance from the center of the lane to the chord connecting the two node points of the horizontal curve does not exceed 0.5 meters (see illustration).
- Use the following steps to determine the number of nodes:
  - Using a mapping tool, draw a lane from the start point of the curve to the end point of the curve.
  - Using the map's measurement tool, measure the perpendicular distance from the center point of the chord to the center of the actual path. This is the maximum perpendicular distance.
- The ratio of perpendicular distances from a chord to the perimeter in bisected arcs converges to 4. Therefore, determine the number of divisions of the chord by dividing the maximum perpendicular distance by 4 until the value is less than the desired error tolerance of 0.5 meters. For example:
  - Original maximum perpendicular distance = 6.48 meters
  - 6.48/4 = 1.62 (division #1 – still exceeds error threshold) – curve is divided in half
  - 1.62/4 = 0.405 (division #2 – is within error threshold) - curve is divided in half a second time

<u>Basis</u>:

- Based on the CTI 4501 v01.01, Connected Intersections Implementation Guide Functional Requirement of 0.5-meter distance from chord to centerline of lane. (CTI 4501 v01.01, Connected Intersections Implementation Guide).

- This approach provides a reproducible method for determining the number of times the curve needs to be subdivided.
- Curves more than 180 degrees and ‘S’ curves should be handled as separate curves.
- When background images are used, the maximum practical zoom level should be viewed to minimize node location error.
- Software tools should enable the user to select the curve end points, maximum perpendicular distance, and set the tolerance to calculate the best fit nodes.

2.3.3.2.13 Step 3 - Guidance #3.17: Node Placement for Through Lane Splits into Through Lane and Turn Lane

A turn lane at an intersection approach is generally split from the through approach. Similarly, turn and through lanes may merge at the intersection egress. Consistency is needed for how these splits and merges are represented in MAP messages.

Guidance:

- At locations where an ingress through lane splits into two lanes, a node point should be located along the centerline path of the through lane at the end point of the turn lane (ingress lane node points start at the stop line). There is no need for the through lane to include an overlapping node point at the location of this node.
- At locations where an egress merge lane joins an egress through lane, a node point should be located along the centerline path of the through lane for the end point of the egress merge lane. There is no need for the through lane to include an overlapping node point at the location of this node. See Figure 14.
- At locations where through lanes split into two or more lanes, overlapping nodes for the end points of each new lane should be created at the separation from the through lane, as illustrated in Figure 14.

Basis:

- Industry feedback and as per the SAE J2735 standard.

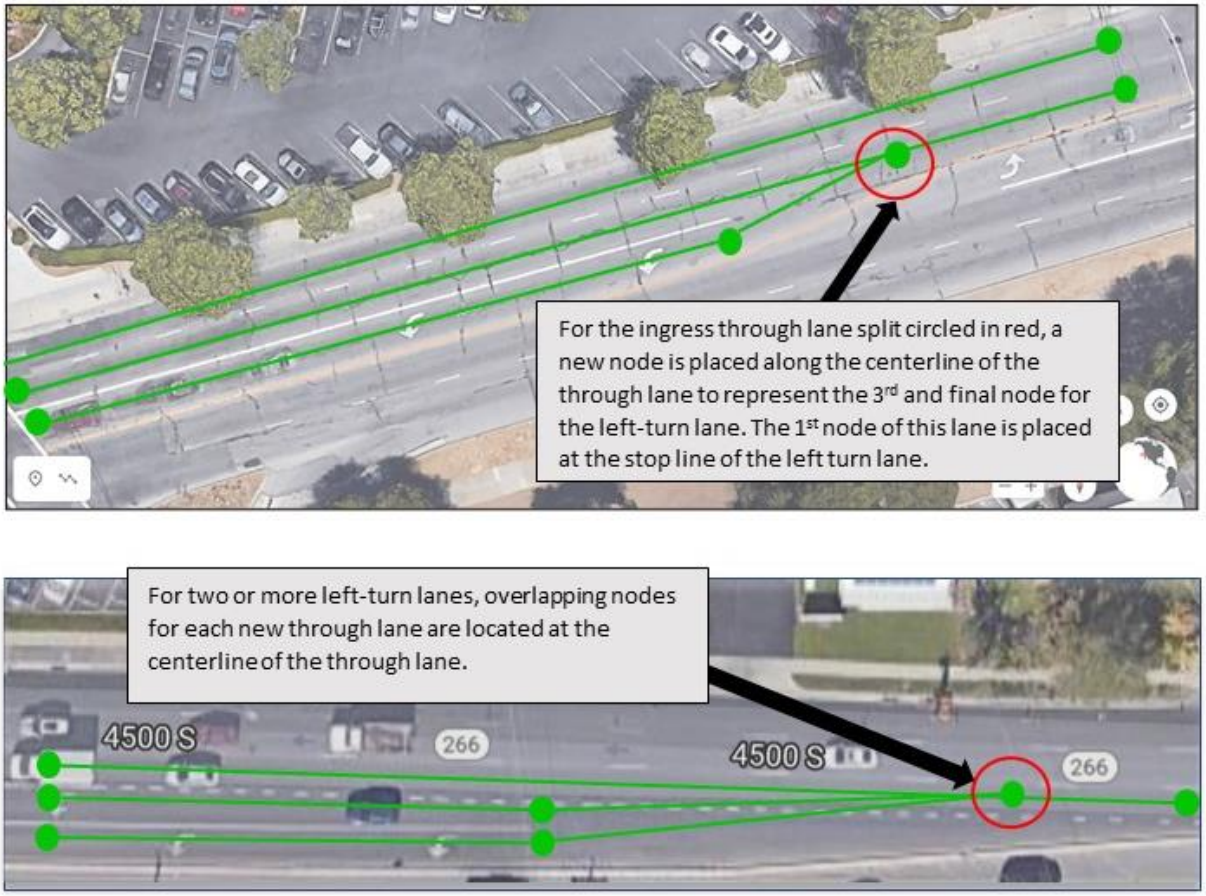


Figure 14: Node Placement for Through Lane Splits
Map source: Google Earth, Drawing Source: Athey Creek

2.3.3.2.14 Step 3 - Guidance #3.18: Non-Signalized Intersections

There are situations where non-signalized intersections occur between two signalized intersections. Most agencies have not developed MAP messages for non-signalized intersections, but as the number of in-vehicle applications increases, it is possible that in-vehicle applications will increasingly rely upon the receipt of MAP messages for non-signalized intersections. Guidance #3.18 describes the use and value of MAP messages for non-signalized intersections and recommends that MAP messages be created for non-signalized intersections at a time when known in-vehicle applications rely upon them. Common examples of non-signalized intersections include:

- A left-turn lane upstream of the connected intersection (e.g., into a driveway);
- An ingress from public or private driveways; and

- Intersections (signalized or non-signalized) where two or more approaches intersect (e.g., a four-way stop).

Any of these examples create an interface with a non-signalized intersection. See Figure 15.

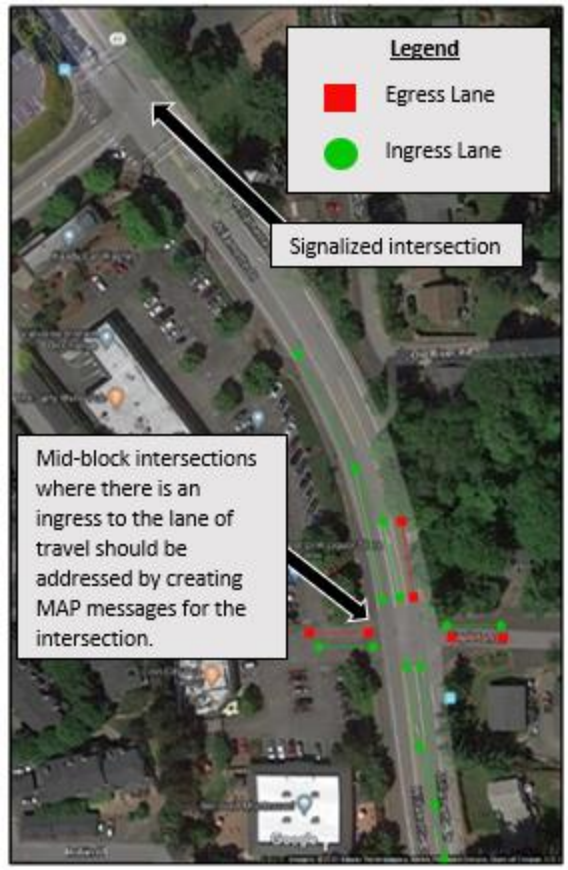


Figure 15: Non-signalized Intersections
Map source: Google Maps, Drawing Source: Athey Creek Consultants

Guidance:

- When there are in-vehicle applications relying upon MAP messages at non-signalized intersections, IOOs shall represent non-signalized intersections by MAP messages.
- Even when the primary flow of traffic is not interrupted by stop signs or signals, turning lanes still represent ingress to the intersection and egress out of the intersection.
- IOOs may develop the MAP message and broadcast it as part of SPaT/MAP broadcasts of upstream or downstream connected intersections.
- The portion of the MAP message that defines the signal groups that each connection is assigned to will not be possible (as there are no signal control phases or groups).

Basis:

- The functions of on-board applications may include vehicle navigation or pedestrian warnings. While not signalized or marked, these are intersections.

2.3.3.2.15 Step 3 - Guidance #3.19: Flyover Lanes

> ! This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

Flyover lanes enable roads to cross with grade separation such that there is no conflict at an intersection. A flyover should not be represented as an intersection in a MAP message. An OBU may however have difficulty locating itself on the proper roadway if there is insufficient elevation information available from the map or from GPS.

Guidance:

- A flyover that crosses a roadway with grade separation and no access should not be represented in the roadway's MAP message.

- If separate MAP messages are created for both the at grade lane(s) and one or more lanes that cross over the at grade lane(s) at some elevation above the intersection, any node point of the at grade lane should be at least 30 meters away from the projected edge of the crossover lane(s).

Basis:

- This will help to minimize vehicles erroneously identifying the wrong road in the location of the crossover.
- A 30-meter distance was selected (without quantitative basis for the value) as a distance that would avoid on-board applications confusing the grade separated roads.

2.3.3.2.16 Step 3 - Guidance #3.20: Parking Lanes

There are potential ambiguities in how to code MAP messages for lanes merging or ending where parking lanes begin.

Guidance:

- Any lane that becomes a parking lane (e.g., egress merge lanes or primary egress lanes) should end before the parking lane begins.
- Merge lanes around parking lanes should end at the location of a node point of the adjacent lane to represent the completion of the merge.

Basis:

- On-board applications may consider the full extent of the merge lane when creating warnings to drivers. The potential for vehicles to be parked in these lanes may create a conflict.
- Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019)

2.3.3.2.17 Step 3 - Guidance #3.21: Node Offsets

Node positions are offsets from the previous node, except the initial node is offset from the MAP message reference point. Seven node offset classes are defined, representing offsets ranging from +/-1 cm up to a complete longitude/latitude coordinate.

Guidance:

- The initial node of a lane is relative to the reference point.
- For an intersection, the initial node for an ingress lane should be placed on the upstream edge of the stop line. If there is no stop line, then the initial lane node should be placed at the upstream edge of the crosswalk. If there is no crosswalk, then the initial node should be placed upstream of the closest edge of the first intersecting lane.
- Subsequent nodes are relative to the previous node—a geo-coordinate node is a new absolute position.
- Software tools should automatically choose the smallest possible node class for each offset.

- Elevation changes from one node to the next are used to indicate changes in elevation. In the interest of conserving MAP message size, changes in elevation less than 20 cm do not need to be indicated when describing the offsets.

Basis:

- As per the SAE J2735 standard.

2.3.3.2.18 Step 3 - Guidance #3.22: Crosswalks

Crosswalks may be described as lanes in the MAP message. Applications may use the boundaries of the crosswalk to issue warnings to drivers of pedestrians in the crosswalk or of protected crosswalk movements.

> ! This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

Guidance:

- When creating crosswalks, crosswalk points are placed at each end of a crosswalk, aligned to the center of the crosswalk.
- Crosswalk lanes are numbered in the same way that vehicle lanes are numbered.
- The crosswalk width would be a delta from the reference lane width.

Basis:

- Based on SAE J2735 standards.
- Additional details about the minimum requirements are not available at this time.

2.3.3.2.19 Turning Lanes

This section contains guidance related to turning lanes.

2.3.3.2.19.1 Step 3 - Guidance #3.23: Channelization and Traffic Islands

Intersections with right turn lanes that involve channelization and traffic islands typically do not have a stop line, nor is there a clear distinction between the ingress and egress. The right turn lane conflicts with the crossing traffic only at the merge and does not directly enter the intersection.

Guidance:

- If a stop line is present, locate the last ingress node point at the upstream start of the stop line.
- If a crosswalk is present after a stop line, locate the first node point of the egress lane immediately downstream of the crosswalk.
- If no stop line is present and a crosswalk is present, locate the last node of the ingress at the start of the crosswalk and the first node of the egress at that downstream side of the crosswalk.
- If no crosswalk or stop line is present, locate the last node of the ingress lane at the merge point with the downstream lane. In this situation, there is no egress lane.

Basis:

- On-board applications may rely on the last node of the ingress lane to identify stopping locations before entering intersections. In this approach, either stop lines or crosswalks provides an interruption between ingress and egress.
- Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019).

Figure 16 shows egress and ingress node points for an intersection with a right turn lane that involves channelization and a traffic island with a stop line. In addition, the node points are shown for a crosswalk where there is no stop line.

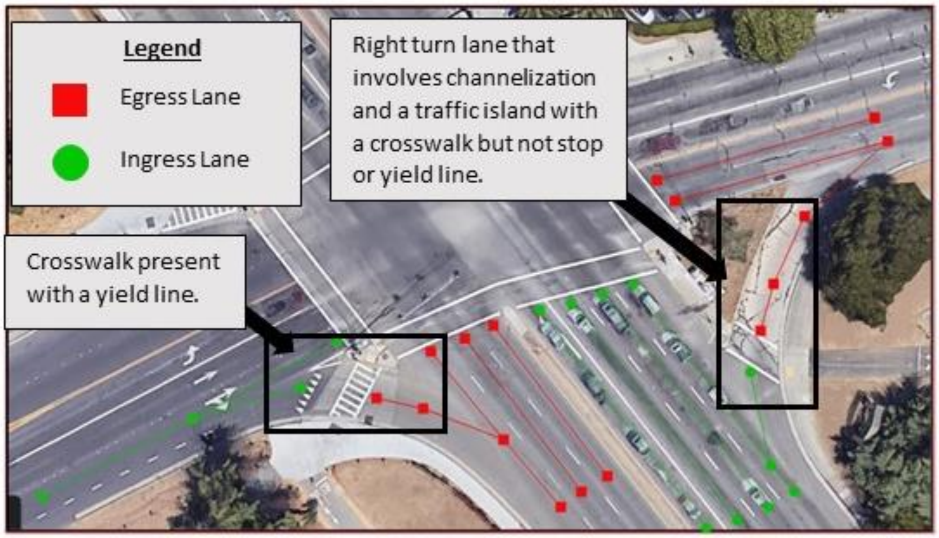


Figure 16: Example node placement for an intersection with channelization and a traffic island
Map source: Google maps, Drawing Source: Athey Creek Consultants

2.3.3.2.19.2 Step 3 - Guidance #3.24: Egress Merge Lanes

Intersections with dedicated or continuous right turn lanes will often merge into other lanes. The merge will typically be either:

- The merge adding a new through lane that is either an auxiliary lane that merges downstream or is a new lane that continues; or
- An immediate merge into an existing lane.

<u>Guidance</u>:

- If the merge point is an immediate merge into an existing lane, the last egress node point should be at the centerline of the existing through lane. Figure 17 shows the egress node points for an intersection where the merge point is an immediate merge. The last node point is at the centerline of the through lane (i.e., an egress out of the intersection).
- If the merge involves a lane add or an auxiliary lane that merges downstream with a downstream merge, the egress lane should extend until a position where the new lane exists and is established. The final egress node point should be in the center of the newly established lane.

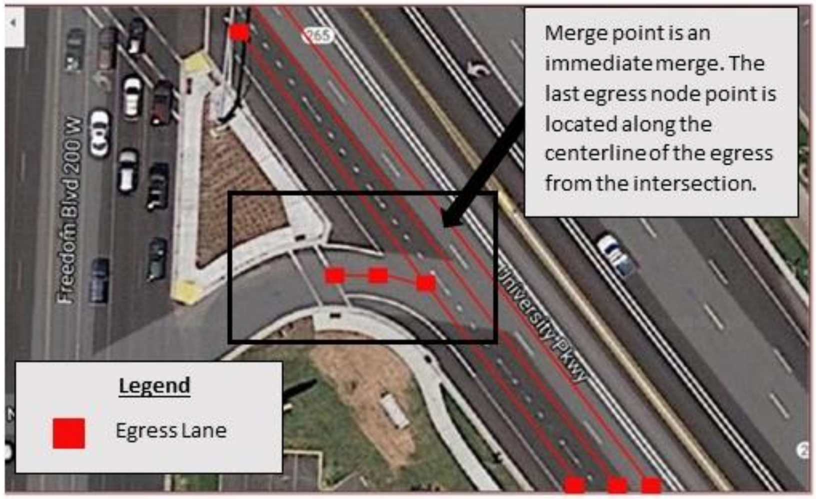


Figure 17: Example egress node placement for an intersection where the merge point is an immediate merge.
Map source: Google maps, Drawing source: Athey Creek Consultants

Basis:

- On-board applications may rely on the last node of the egress lane to identify conflicts/merges with other flows of traffic.
- Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019).

2.3.3.2.19.3 Step 3 - Guidance #3.25: Mid-Block Left-Turn Lanes

There are situations where the ingress lanes of a connected intersection separate into a left-turn lane that allows traffic to turn left before the signalized intersection (e.g., into a shopping area).

Guidance:

- Mid-block situations that include left-turn lanes should be represented by a separate MAP message, with ingress and egress lanes.
- Even when the primary flow of traffic is not interrupted by stop signs or signals, these lanes still represent a left-turn ingress to an intersection, whether the connection is to another road or a parking lot.
- IOOs may develop the MAP message and broadcast it as part of SPaT/MAP broadcasts of upstream or downstream connected intersections.
- The portion of the MAP message that defines the signal groups that each connection is assigned to will not be possible (as there are no signal control phases or groups).
- See also Guidance #3.18: Non-signalized Intersections.

Basis:

- The functions of on-board applications may include vehicle navigation or pedestrian warnings. While not signalized or marked, these are intersections.

2.3.3.2.19.4 Step 3 - Guidance #3.26: Two-Way Left-Turn Lanes

> **!** This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

Two-way left-turn lanes (TWLTL) allow traffic performing left turns in both directions to use the median, creating an ambiguity in how these lanes are coded in MAP messages. See Figure 18.

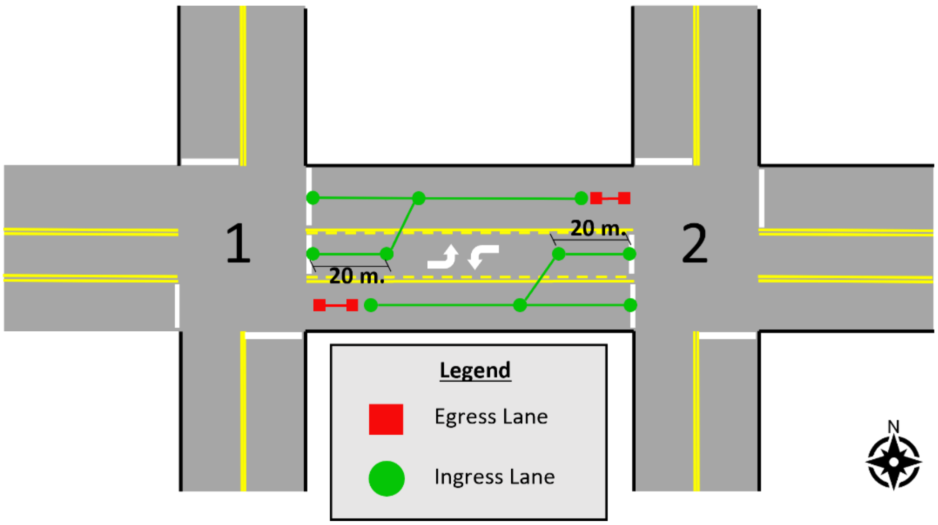


Figure 18: Two-way left-turn lanes
Source: Athey Creek

<u>Guidance</u>:

- TWLTLs should be treated as ingress lanes (left turn lanes) into the intersection where the left turns will occur. See Figure 18 where the TWLTLs are coded as left turn ingress lanes into Intersections 1 and 2. Note that separate MAP messages would still be created for each intersection and there would not be a separate MAP message for the TWLTLs.
- The length of the ingress shall extend a distance such that the opposing left-turn (other direction of travel) lanes do not overlap (a 20 meter ingress length was used in the Franklin County Ohio Smart City application). If the total length of the TWLTL is less than 40 meters, reduce the length of both turn lanes to one-half of the total length.

<u>Basis:</u>

- The approach with the least issues is to represent the left-turn movements. Without a designated end to the turn bay, a distance for the left-turn lane must be assigned.
- Approach used and documented in the Ohio Smart City project (Smart City Intersection Digitization Update, 2019).

2.3.3.3 Lane Use Descriptions

Lane use descriptions guidance includes direction of travel and lane use variations such as revocable and restricted lanes.

2.3.3.3.1 Step 3 - Guidance #3.27: Direction of Travel

The first node of all ingress and egress lanes is the node closest to the intersection. Subsequent node offsets are calculated moving away from the intersection for both ingress and egress lanes. For this reason, it is not possible to determine the direction of travel solely by the ordering of the node points. To enable OBUs to determine a lane's direction of travel, each lane in an intersection MAP message is assigned to be either:

- Ingress path (i.e., travel is in the direction from the last node point to the first node point of the lane;
- Egress path (i.e., travel is in the direction from the first node point to the last node point of the lane.

Each lane in a MAP message includes a bit string describing the direction of travel (Lane Direction). An ingress path is identified by the bit value (0), and egress path is identified by the bit value (1) in the Lane Direction Bit String. Note that if a lane allows both directions of travel, both the ingress and egress bit values would be included. This value may be used by an OBU to determine the lane of travel and/or to identify wrong way operations.

Guidance:

- Direction is relative to the stop line, i.e., ingress means the first node is closest to the intersection.
- Ingress and egress are indicated by separate logical flags.
- Bi-directional travel (including pedestrian crosswalks) sets both ingress and egress logical flags.
- The assignment of the proper bit identifier is a function that MAP Creation Tools would typically perform automatically. Users of tools should be careful to properly identify the direction of travel by placing the first node at the boundary of the intersection and properly identifying if the lane is an ingress path or an egress path.

Basis:

- As per the SAE J2735 standard.

2.3.3.3.2 Step 3 - Guidance #3.28: Lane Use Variations

When intersections include lanes with usage that varies at different times (e.g., revocable, restricted), the MAP message must provide lane descriptions to accompany the SPaT message indicating these variations of use.

Guidance:

- For any lanes that have variations of use (reversible lanes, turn restrictions, parking restrictions), the MAP message should define separate lanes for each variation of usage. Each lane should be described by lane attributes as 'revocable'.
- If the revocable attribute is not reported, the lane is assumed to always be present and SPaT messages will not successfully describe variations in use.

- In parallel to creation of lane use variations, the user creating the message should verify that the SPaT message is broadcasting status of all revocable lanes.

Basis:

- The SAE J2735 SPaT message will be used to report the status of revocable lanes as either activated or not. If multiple lanes are described for each revocable lane, this status can describe it as active or not active.

2.3.3.3.3 Step 3 - Guidance #3.29: Lane Types

The lane type is a required field in the MAP message and is used to indicate the type of lane. The following are the options for lane types:

- Motor vehicle lane;
- Pedestrian crosswalk lane;
- Sidewalk lane;
- Bicycle lane;
- Median lane;
- Striping lane;
- Tracked vehicle lane (e.g., rail, trolley); and
- Parking lane.

Guidance:

- Follow SAE J2735 structure when identifying the correct lane type for each lane, using the following guidelines:
  - Ingress and egress lanes used by vehicles should be assigned as motor vehicle lanes;
  - Crosswalks that cross lanes of the intersection should be assigned as pedestrian crosswalk lanes;
  - Sidewalks that do not cross vehicle lanes (including pedestrian landings on curb corners) should be identified as sidewalk lanes;
  - Lanes for the travel of bicycles should be identified as bicycle lanes;
  - Lanes in and around the intersection that generally do not have any type of traffic should be identified as median lanes;
  - Striping lanes are used when there is a need to describe the path of a connection through the intersection (e.g., identifying the lane lines of a double left-turn lane);
  - Any lanes that describe movement of trains, trolleys, or other tracked vehicles should be described as tracked lanes. Note that when motor vehicle lanes are shared with light rail, the approach would be to develop two lanes: a motor vehicle lane and a tracked lane.
  - Any lanes that permit parking should be identified as parking lanes.

Basis:

- SAE J2735 definition of lane types.

2.3.3.4 Connections and Signal Groups

This section provides guidance for connections and signal groups including defining connections and maneuvers – motor vehicle lanes, defining connections – sidewalk lanes to crosswalk lanes, and allow lane maneuvers.

2.3.3.4.1 Step 3 - Guidance #3.30: Defining Connections and Maneuvers – Motor Vehicle Lanes

Connections between motor vehicle lanes (typically ingress lanes and egress lanes) are essential aspects of the MAP message. It is important that each possible connection be identified, see Figure 19.

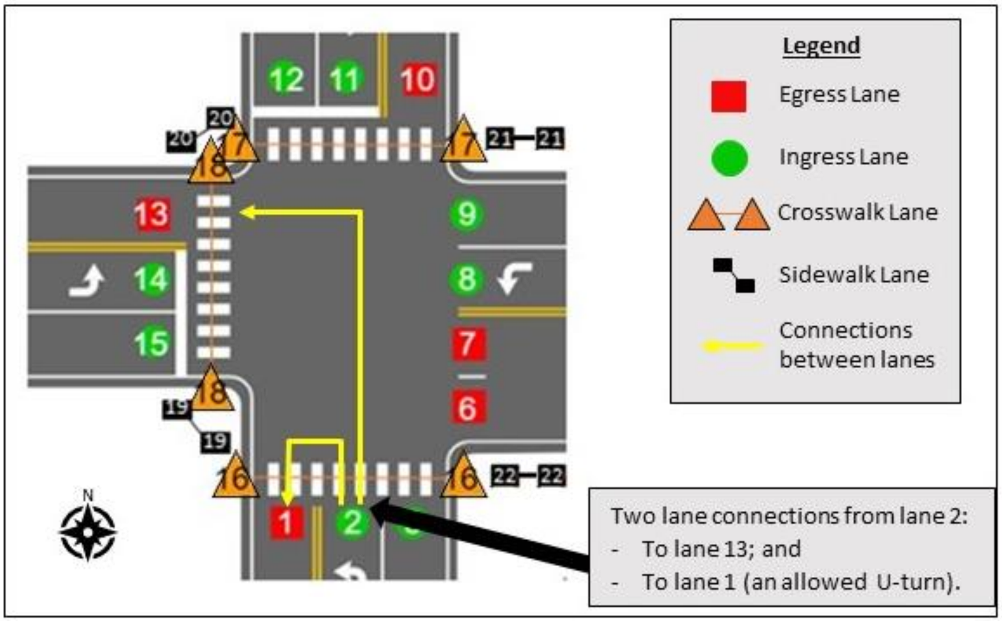


Figure 19: Connections
Map source: Google Maps, Drawing Source: Athey Creek Consultants

Connections are defined for each lane. A separate connection is created for each possible movement from the lane (e.g., an ingress lane may have two or more connections (e.g., a connection to the through egress lane, a connection to the right-turn egress lane, and possible additional connections to a left-turn egress lanes or U-turn lanes if allowed from the through lane). Each connection will be defined by the following key elements:

- Connecting Lane or Remote Intersection:
  - Connecting lane is the lane that the ingress lane is connected to and will be an egress lane out of the intersection.
  - A remote intersection is the reference ID of a remote intersection. This should be used if the MAP creator wants to show a relationship to a downstream intersection. It is not mandatory in SAE J2735 to define connections to remote intersections.
- Maneuvers – the maneuvers that are allowed between the ingress lane and connecting lane.
- Signal Group – the channel/signal group that describes the current signal indication for this connection.

- Connection ID – An optional numeric value used to reference the connection for specific uses.

Guidance:

- When creating MAP messages, enter all connections between ingress and egress lanes.
  - Note: The assignment of possible connections is a function that MAP Creation Tools would typically support through a user interface (e.g., select an ingress lane and then select all connections that this lane connects to). Users of tools should be careful to properly use this feature and should ensure this feature is included in tools they select.
  - In situations where U-turns are permitted or protected, MAP creators should be careful to identify the egress lane by which vehicles would exit the intersection in the U-turn movement.
- When assigning maneuvers to the connections, take care to identify the maneuver that describes the connection.
  - Note: The assignment of the maneuver is a function that MAP Creation Tools would typically support through a user interface (e.g., when creating the connection, allowing MAP creators to select the appropriate maneuver). Users of tools should be careful to properly use this feature and should ensure this feature is included in tools they select.
- When assigning the signal group, assign the appropriate signal group number (also described as the channel number) for each connection, as assembled in Step 1 (e.g., gathered from the traffic engineer or signal design plan).
- When entering a Connection ID, follow any local numbering approaches. It is possible for two connections to have the same ID.
- The remote intersection reference ID is required when a lane connects to a lane defined for an adjacent connected intersection. If the adjacent intersection is not a connected intersection, the remote intersection reference ID is not mandatory.
- Connections to remote intersections must be from egress lanes out of the intersection to ingress lanes into the adjacent intersection. It is not advised to avoid defining egress lanes and to connect directly from ingress lane into one intersection to the ingress lane into an adjacent intersection.

Basis:

- Connecting Lanes, Remote Intersections (when applicable), Maneuvers, and Signal Groups are all required elements in the CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.3.3.4.2 Step 3 - Guidance #3.31: Defining Connections – Sidewalk Lanes to Crosswalk Lanes

Connections between sidewalk lanes and crosswalk lanes are used in the MAP message to describe when “walk” indicators allow movement from the curb to the crosswalk. This would be useful if the MAP message is used to determine when pedestrian movements are protected by the pedestrian indicator, either to advise pedestrians or to warn vehicles approaching a crosswalk.

Creating the connections between sidewalk lanes and crosswalk lanes is another example of defining the connections for a lane. In this case, the sidewalk lane serves as the ingress lane, and a connection is created for each crosswalk for which the sidewalk lane connects. A separate connection is created for each possible movement from the sidewalk lane (e.g., a sidewalk lane on a corner will often have two connections to the two crosswalk lanes at the curb). Note that the connection is always made such that the sidewalk lane is the ingress lane, and the crosswalk lane is the egress lane. Each connection will be defined by the following key elements:

- Connecting Lane – the crosswalk lane ID that the sidewalk lane is connecting to.
- Maneuvers – the maneuver would be defined as a straight movement).
- Signal Group – the channel/signal group that describes the pedestrian crosswalk status for this connection.
- Connection ID – A numeric value used to reference the connection for specific uses.

<u>Guidance</u>:

- When creating MAP messages, select each sidewalk lane and create the appropriate connections with crosswalk lanes.
    - Note: The assignment of possible connections is a function that MAP Creation Tools would typically support through a user interface (e.g., user selects a sidewalk lane and then selects the crosswalk lane for the connection). Users of tools should be careful to properly use this feature and should ensure this feature is included in tools they select.
- When assigning maneuvers from the sidewalk lanes to the crosswalks, identify the maneuver that describes the connection. This is understood to be a straight movement.
- When assigning the signal group, assign the appropriate signal group number (also described as the channel number) as collected in Step 1 (e.g., gathered from the traffic engineer or signal design plan).
- When entering a Connection ID, follow any local numbering approaches. It is possible for two connections to have the same ID.

<u>Basis</u>:

- SAE J2735 requires explicit identification of all connections between lanes, including crosswalk and sidewalk lanes.

2.3.3.4.3 Step 3 - Guidance #3.32: Allowed Lane Maneuvers

A mandatory element of the definition of each lane is to define all allowed maneuvers for each lane. For ingress lanes, this includes all maneuvers that are allowed at the stop line (e.g., straight allowed, right allowed, etc.) for egress lanes, this means all maneuvers that are allowed at the most downstream (final) node of the egress lane (e.g., straight allowed). The following are the options for maneuvers:

- Straight allowed;
- Left allowed;
- Right allowed;
- U-turn allowed;
- Left-turn on red allowed;
- Right turn on red allowed;
- Lane change allowed;
- No stopping allowed;
- Yield always required;
- Go with halt; and
- Caution.

Guidance:

- Follow SAE J2735 structure when identifying the correct lane type for each lane, using the following guidelines:
  - When identifying the maneuvers for a lane, include all possible movements;
  - When describing maneuvers for sidewalk lanes that connect to crosswalks, use "straight allowed";
  - When describing crosswalk lanes, use "straight allowed";
  - Recognize that the identification of all possible maneuvers assigned to a specific lane is different from the assignment of the specific maneuver that is assigned to a connection (as discussed in Guidance #3.29: Lane Types and #3.30: Defining Connections and Maneuvers – Motor Vehicle Lanes). This is a comprehensive list of maneuvers possible from this lane, whereas the other is assigning one maneuver to each connection.

Basis:

- The CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.3.3.5 Other

2.3.3.5.1 Step 3 - Guidance #3.32: Multiple Intersections in Close Proximity

There are various locations where the signalized intersection is in close proximity to one or more other intersections or traffic control activities. Creation of MAP messages can be challenging, and the industry would benefit by consistent coding of these situations.

Signal control may be performed by one common controller or separate controllers. Even if one controller is used, a typical phase pattern may be used to protect specific movements (e.g., signalized intersection with rail crossings may locate the stop line before the rail crossing with phase designations to allow any queues to clear, creating additional phases).

Guidance:

- If multiple intersections are in close proximity and use one common signal controller, develop an overall MAP message for all approaches into and out of the common intersection. Phase designations may vary by agency (e.g., use of overlaps or exclusive movements during train detections).
- If two or more intersections are in close proximity, and have separate controllers that are synchronized, separate MAP messages should be used.
  - The ingress for the downstream intersection may overlap the egress lane for the upstream intersection.
  - In situations where there is an upstream signalized non-connected intersection that does not allow the ingress lane to the downstream intersection to be long enough to provide at least 10 seconds of vehicle travel time without extending into the conflict area of the upstream intersection, consider creating a MAP message for the upstream intersection and broadcasting the MAP message using the RSU for the downstream intersection (i.e.,

the downstream connected intersection will broadcast MAP messages for both intersections). This will enable applications (e.g., signal priority applications) to recognize they are approaching the signalized intersection sooner and begin determining if they need to send a priority request.

Basis:

- MAP messages assign movements to specific signal groups.
- The CTI 4501 v01.01, Connected Intersections Implementation Guide recommends that a downstream connected intersection broadcast the MAP information for upstream non-connected intersections.

2.3.3.5.2 Step 3 - Guidance #3.33: Pre-Signals

> ! This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

There are locations where an intersection (i.e., signalized junction of two highways) is in close proximity to a railroad crossing. In these situations, one or more approaches to the intersection may include a traffic signal to stop traffic prior to the crossing and/or avoid a queue backing up to the crossing. The signals located on the approach to the intersection may be Pre-Signals that are controlled by the common controller that is used for the intersection. In contrast, Queue-Cutter Signals are typically operated by separate controllers and considered mid-block intersections.

Locations with pedestrian or bicycle crossings in advance of the primary intersection may also operate pre-signals.

Creation of MAP messages can be challenging and there may not be correct or incorrect ways to code pre-signals, however consistent coding of these situations will be beneficial.

Guidance:

- In situations where an approach to a connected intersection includes a pre-signal and the pre-signal is operated by the same controller as the intersection
  - The approach should include an ingress lane with the first node of the ingress lane at the stop line controlled by the pre-signal, with connections assigned to the appropriate signal group of the intersection signal. See Figure 20.
  - The approach should include a second ingress lane, with the first ingress node at the stop-line controlled by the signal at the intersection, with connection assigned to the appropriate signal group of the intersection signal.
  - The pre-signal ingress lanes "connects to" fields should be populated with the lane number of the ingress lane that follows the pre-signal stop line.
  - The second set of ingress lanes "connects to" fields should be populated with one or more lane numbers of the egress lanes out of the intersection that represent allowed movements.

Basis:

- Avoids possible confusion by OBU applications expecting Ingress to egress connections.
- Vehicles waiting in the area beyond the pre-signal could benefit from SPaT information to support on-board applications.

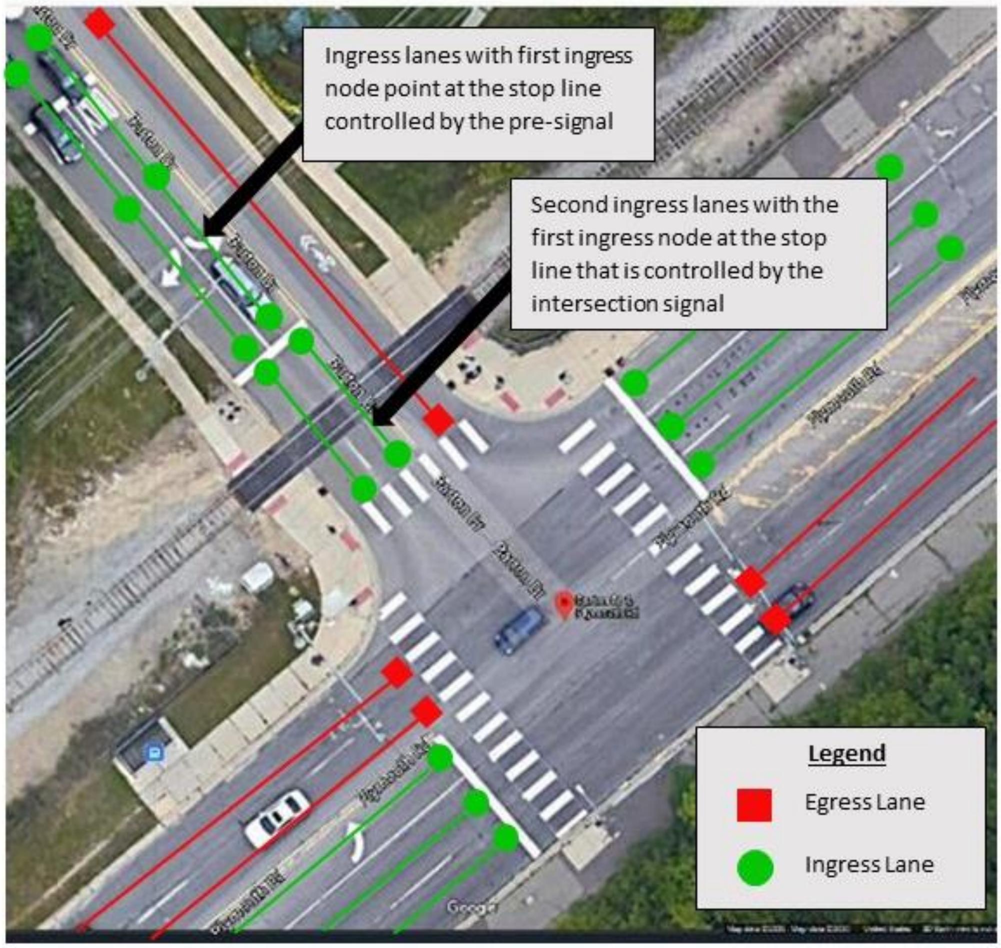


Figure 20: Pre-Signals
Map source: Google Maps, Drawing Source: Athey Creek Consultants

2.3.3.5.3 Step 3 - Guidance #3.34: Divided Highway – Multiple Signals Per Approach

There are locations where at least one highway intersecting at an intersection (i.e., signalized junction of two highways) is a divided highway. In situations where space is allowed between the lanes of the divided highway (e.g., often referred to as "storage lanes") vehicles may be stopped at red lights in this interim location. When there is:

- A first signal-controlled stop line for any approach and
- A second signal-controlled stop line for the same approach.

The creation of MAP messages can be challenging, and the industry would benefit by consistent coding of these situations. See Figure 21.

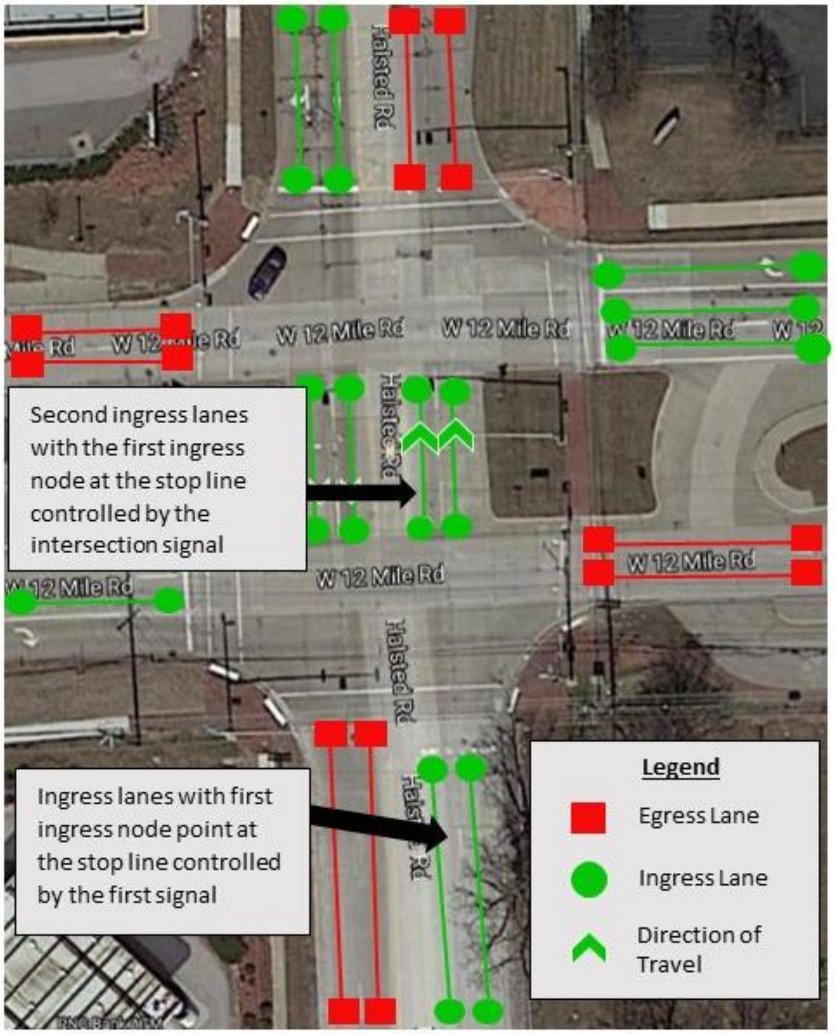


Figure 21: Divided highway – multiple signals per approach
Map source: Google Maps, Drawing source: Athey Creek Consultants

<u>Guidance</u>:

- In situations where a storage lane exists within a divided highway and vehicles encounter a first signal-controlled stop line and a second signal control stop line, with space in between, and:
  - The first signal-controlled stop line is at an intersection that either allows turns or does not allow turns.
  - Vehicles proceeding straight at the first signal-controlled stop line encounter a second signal-controlled stop line before exiting the intersection.
  - All signals are controlled by the same signal controller

  Then, the following recommendations apply:
  - An ingress lane is recommended to be placed on the approach to the first signal with the first node point at the stop-line before the first signal.
  - A second ingress lane is recommended to be in the area between the divided lanes, with the first ingress node at the second signal-controlled stop line.

- The "connects to" field of the ingress lanes before the first signal are recommended to be populated with one or more lane numbers of the ingress lanes in the storage area, as well as any allowed movements at the first signal (e.g., if right-turn is allowed at the first signal).
- The "connects to" fields of the ingress lanes in the area between the divided lanes should be populated with one or more lane numbers of the egress lanes out of the intersection that represent allowed movements (e.g., left-turn, straight, etc.).

Basis:

- Ingress lane to ingress lane connections are allowed in SAE J2735.
- Vehicles waiting in the area between the divided lanes could benefit from SPaT information (e.g., crosswalk status, time to green start).

2.3.3.5.4 Step 3 - Guidance #3.35: Jug Handle Intersections

There are various locations where the left turn is accomplished by exiting to the right into a "jug handle" lane and turning left outside of the intersection (typically at a non-signalized stop sign).

Guidance:

- A MAP message should be created for the primary intersection.
    - All movements allowed at the intersection should be included in the MAP message.
- The 'top of the jug handle' (green circle in Figure 22 below) may be created as a separate MAP message (typically if signalized) or may not depending upon local deployment. These movements would not be part of the primary intersection MAP message.
- The exit ramp (yellow circle in Figure 22 below) would not be described by a MAP message.

Basis:

- Distinct intersections need their own intersection definitions in a MAP message.

Figure 22 is an aerial view of a jug handle intersection, with circles identifying the references made in the guidance.

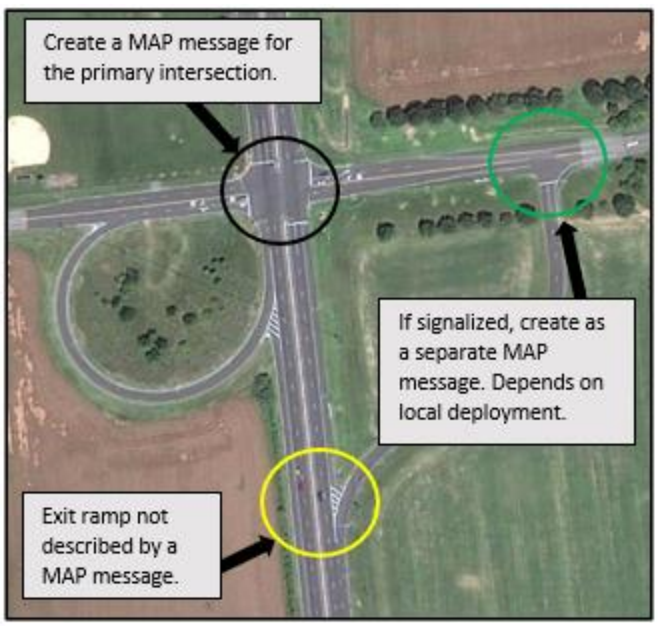


Figure 22: Aerial view of jug handle intersection
Map source: Google Maps, Drawing source: Athey Creek Consultants

2.3.3.5.5 Step 3 - Guidance #3.36: Neighborhood Streets with Parking Lanes

> This topic has seen limited deployment to date and requires additional experience and research to determine more definitive guidance.

It is common that neighborhood roads do not have a painted centerline lane stripe, and often allow parking on one or both sides of the road. In these situations, vehicles often drive around parked cars and there may not be two full lane widths for active travel in addition to the parked cars. The determination of the lane width and centerline of the lane can be interpreted differently by different MAP creators. Since the lane width is important for in-vehicle applications to determine their lane of travel, an approach is needed to identify the full lane of travel that vehicles may occupy along these routes.

Guidance:

- For an ingress lane of a street without a painted centerline and where parking is allowed, the width of the lane should be from the sidewalk curb to a distance away from the opposite sidewalk curb that would allow for parked cars (see Figure 23).
- In this situation, the ingress and egress lanes will overlap each other.
- If there is a need to create parking lanes, the location on either side of the road where parking is allowed could be described as parking lanes. If these were created, these parking lanes will overlap with the lane of travel.

Basis:

- Based on requirements described in the CTI 4501 v01.01, Connected Intersections Implementation Guide.

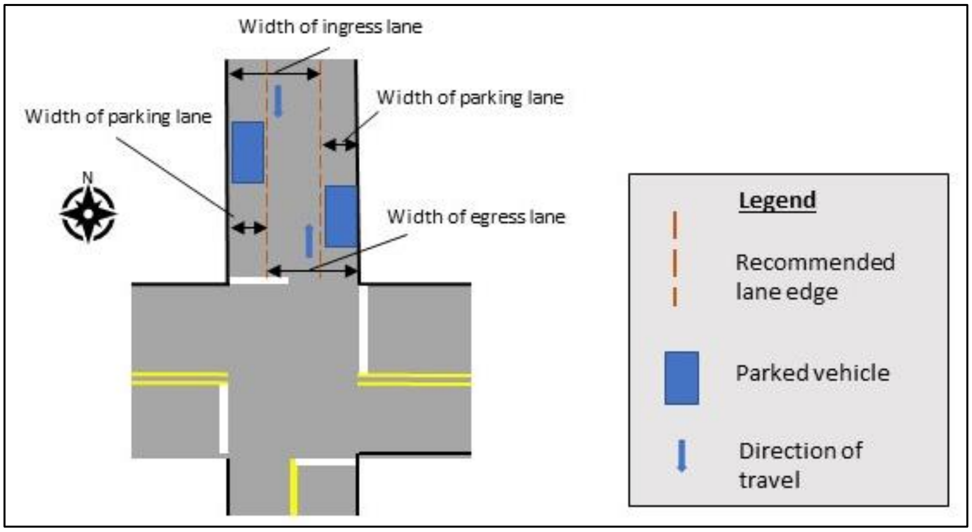


Figure 23: Illustration of Ingress/Egress Lanes for a Neighborhood Street with Parking Lanes
Source: Athey Creek Consultants

2.4 Step 4 - Visual Validation

Step 4:
Visual Validation

During Step 4, the MAP creator is suggested to perform a visual validation of the node points after that MAP content has been created. This could include extracting the node points that were created in Step 3 and overlaying them on a mapping product. Preferably, the mapping product used in the overlay is different from the mapping tool used in the creation.

2.4.1 Objective

There are two primary objectives for Step 4, summarized as follows:

- Inspection of intersection geometry and movements to confirm that all intersection approaches, crosswalks, and designated turn lanes are represented in the MAP content.
- Visual inspection of accuracy of node points to confirm that nodes are properly placed. Stakeholders should also check again that the aerial imagery used to create the MAP message used up-to-date images that accurately reflect the intersection. It is recognized that visual validation (e.g., using a tool such as Google Earth) will not provide a quantitative test of whether each node is 0.2 meters accurate, but it could identify any gross errors in node placement.

2.4.2 Step 4 Guidance

This section describes overall guidance for visual validation of the node points after the MAP content has been created.

2.4.2.1 Step 4 - Guidance #4.1: Visual Validation

Practitioners have noted the importance of re-examining the nodes that were created both to look for any missing movements, lanes, crosswalks, etc. and to observe possible accuracy discrepancy.

<u>Guidance:</u>

- Following Step 3 – Place Nodes and Create MAP Content, MAP creators may extract the node points of the MAP content in a format compatible with mapping tools they have available. For example, the USDOT Tool is capable of extracting a KML file of the node points.
- MAP Creators may import output files containing the node points into their preferred tool. For example, Google Earth allows the import of KML files.
- MAP creators may look for any missing approaches, lanes, crosswalks by comparing overlaid node points to the signal phase data using intersection condition diagrams as a source for the signal phase data.
- MAP creators may use visual observations to make best judgements about the accuracy of node points. Suggestions for consideration during the visual inspection include:
    - Do nodes along a curve appear to accurately represent the curvature of the road with tolerable deviations?
    - Do nodes appear to be in the center of the lane?
    - Does the first ingress node appear to be at the upstream edge of the stop line?
    - Does the first egress node appear to be at the downstream edge of the crosswalk?
    - Does the numbering of nodes reflect consistency?

  - Where a lane separates into two (e.g., through lane splitting off a left-turn lane) are two overlapping nodes representing the location where the lane splits?

<u>Basis:</u>

- Visual validation was a step described by interviewees during the outreach process as valuable to confirm proper assignment of all nodes and lanes.

2.5 Step 5 - Convert to SAE J2735 Format

Step 5:
Convert to SAE J2735 Format

Step 5 converts the MAP message content assembled in Step 3 – Place Nodes and Create MAP Content into the format specified by SAE J2735 for MAP messages. The step also should check for errors in the message and produce a human-readable version of the MAP message content to aid in reviewing and revising the message content.

2.5.1 Objective

The objective of this step is to encode the physical and logical roadway descriptive information from Step 3 into the SAE J2735 format so that it is usable by roadside and on-board equipment.

At a minimum, the required and non-default value elements of the MAP message geometry must be completed. This includes intersection and roadway geometry that consist of lanes, vehicle types, and traffic controls.

There can be intermediate encodings of the collected information, but the ultimate output is an UPER processed MAP message that can be broadcast, typically by roadside units (RSUs). Processed MAP messages can also be broadcast through network communications.

It is important to note that the conversion process is somewhat dependent on the destination device. Some vendors may take a specifically formatted input that an RSU converts to the SAE J2735 UPER format, while others may require MAP messages externally encoded to that format.

Beginning with the Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard, interfaces are available to store and forward messages at a regular interval and to immediately forward a message received over the RSU's agency network connection. These interfaces accept either an encoded message directly transmitted or a text-formatted message to be encoded by the RSU and then transmitted.

There is also a dependency on the creation tool used, if any. Different tools may have the feature to export or import a data file format that is not the UPER encoded output. These additional types of data files may be in a more human-readable (if not understandable) form and used for configuration management.

2.5.2 Step 5 Guidance

This section includes guidance for converting to SAE J2735 format as shown in Table 7 below.

Table 7: Step 5 – Convert to SAE J2735 Format: Guidance List

Step 5	Guidance #5.1	Convert to SAE J2735 Format
	Guidance #5.2	Test MAP Message Completeness and Structure

2.5.2.1 Step 5 - Guidance #5.1: Convert to SAE J2735 Format

UPER encoding of information is complex at best, and software that complies with UPER and SAE J2735 standards should be used.

The USDOT Tool serves as both a graphical manipulation interface to roadway geometry and also provides the means to save each configuration in a JSON format as well as a hexadecimal encoded string of characters.

Of those interviewed, most MAP message creators used software that creates a text-based encoding either used directly by an RSU or in conjunction with the USDOT ISD tool to produce the needed output.

Guidance:

- The recommendation is to use MAP creation software that can error check against the SAE J2735 MAP message standard, create a human readable text file for configuration management, and directly create the required UPER format, or export to an intermediate format that can be read by the USDOT ISD tool to produce the necessary output.

Basis:

- The MAP message must conform to the requirements of the CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.5.2.2 Step 5 - Guidance #5.2: Test MAP Message Completeness and Structure

An online utility has been created by CAMP that provides a mechanism for uploading MAP messages to the utility so that the utility can process the details of the MAP message to determine completeness and structure, as defined by the CTI 4501 v01.01 Connected Intersection Implementation Guide. The CTI 4502 v01 Connected Intersections Validation Report describes data collection and analysis for field validation, as conducted during the 2021 ITE Connected Intersection Program validation phase, including information about the CAMP SPaT/MAP Utility used to verify MAP messages. The CAMP SPaT/MAP Utility can:

- Provide a visual display of all ingress/egress lanes and connections.
- Provide a “pass/no pass” report of all required data elements.
- Confirm the required data elements are included in the MAP message.
- Confirm the data elements are properly coded in the SAE J2735 standard format.

Guidance:

- The recommendation is to access and use the CAMP SPaT/MAP Utility to upload the created MAP message, in order to verify its completeness and structure.

Basis:

- The MAP message must conform to the requirements of the CTI 4501 v01.01, Connected Intersections Implementation Guide.

2.6: Step 6 - Load to RSU

Step 6:

Load to RSU

Step 6 guidance includes loading the MAP message to the RSU.

2.6.1 Objective

The objective of Step 6 is to load the MAP message created in Step 5 to the RSU or network location from where it is staged for broadcast. The message will be in either the final SAE J2735-specified UPER format, or in another format required by the RSU manufacturer, the V2I Hub, or the V2I network management services. Loading the message will require access and permissions to the RSU through an agency-maintained set of accesses and permissions.

2.6.2 Step 6 Guidance

This section provides guidance for loading the MAP message to the RSU.

2.6.2.1 Step 6 - Guidance #6.1: Load to RSU

There may be significant variability in the message loading process, depending on the network configuration, RSU manufacturer, use of a V2I Hub, or use of other management services for V2I messaging. Some of the loading variations using a backhaul network may put messages directly on an RSU to be repeated, on an intermediate device that repeats the message, or even on a common server that repeats different messages across the network to connected RSUs. There is even a network-less scenario where messages are loaded to roadside equipment via local Wi-Fi or even a USB drive.

Approaches to security credentialling, as defined in the CTI 4501 v01.01, Connected Intersections Implementation Guide, will eventually require that MAP messages are digitally signed with a valid certificate. Final procedures for performing this are still being defined by other efforts at the time this document is being published.

Guidance:

- Review the RSU manufacturer instructions for configuring and installing messages on their devices.
- If a test RSU is available, verify that the MAP message(s) can be loaded to a test RSU matching the field configuration.
- Retain copies of the prior MAP message(s) on the field RSU before loading or overwriting.
- Perform security credentialling by getting the MAP message digitally signed with a valid certificate.
- Load the message(s) to the RSU.
- Note any installation messages and errors.
- Resolve any issues, reworking the messages, conversion, and loading as necessary.

2.7 Step 7 - Field Validation

Step 7:
Field Validation

Step 7 focuses on conducting a field validation to ensure MAP messages are correct.

2.7.1 Objective

The objective of Step 7 is to validate and verify MAP messages at the intersections where they are to be deployed. It verifies that the appropriate MAP message(s) are being broadcast and confirms that MAP messages are correct, appropriate, and available for their intended deployments.

There are two levels of verification possible in this step. The first level is to confirm that the received messages are appropriate for the RSU point-of-presence and match what was loaded to the RSU. The second level is to verify the encoded geometry elements are consistent with the physical infrastructure at the time of receipt.

The requirements for this step include:

- MAP messages deployed and being broadcast at the locations to validate, or
- At a minimum, MAP message contents to be confirmed in the field (without broadcast).
- Performance criteria for:
    - Node point and path accuracy, and
    - Reliability of perceived lane location.

2.7.2 Step 7 Guidance

This section includes guidance for field validation.

2.7.2.1 Step 7 - Guidance #7.1: Field Validation

Verifying received MAP messages against expected MAP messages is a straight-forward process. An OBU in geo-tagged data logging mode can be driven along roadways and through intersections with associated MAP messages for vehicle position driving data collection. The logged messages can then be quickly compared to source messages and their reference points to confirm that the OBU is able to accurately determine the lane of travel and detect other errors.

A cooperative effort between automakers and Utah DOT led to a field validation process supported by an automated utility, which is described below.

Guidance:

- For vehicle position driving data collection, follow the data collection method described in the resource titled "Connected Intersection MAP Data Assessment Supporting Basic Red Light Violation Warning" 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. CAMP estimates the drives for data collection to take 2.5 - 3 hours. 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 Connected Intersection MAP Data Assessment Supporting Basic Red Light Violation Warning. Figure 24 illustrates the required and optional sets of driving runs for multiple lane configurations.

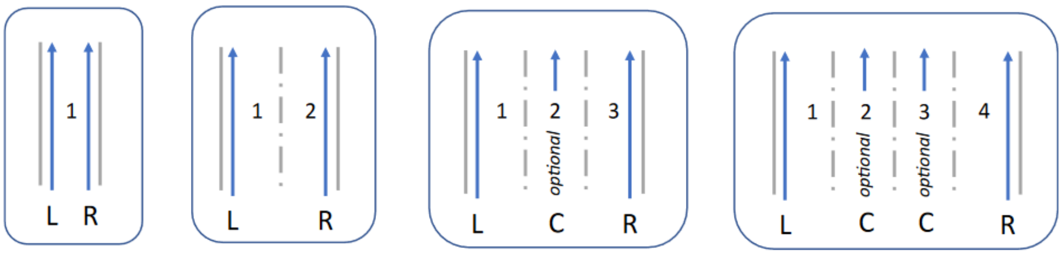


Figure 24: Illustrative Sets of Driving Runs for Vehicle Position Driving Data Collection

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

- Uploading data to the CAMP “SPaT/MAP Utility, version 1” on-line tool then allows:
  - Visual inspection of vehicle path data compared to bounding boxes of each lane
  - Path Data Analysis, which displays:
    - Purple dots if outside lane
    - Yellow dots if on left ¼ of lane
    - Blue dots if in middle ½ of lane
    - Cyan dots if on right ¼ of lane
- For each connected intersection approach, a Pass/Fail is generated. Pass is if MAP matches to group of through lane movement for at least 7 of 8 runs. A decision tree is available that supports determination of whether the MAP message may be skewed left or right or lane width is too narrow or wide.
- Position correction using RTCM data might be needed for the OBU to operate properly to perform this test.
- The second level of verification can be much more in-depth. MAP messages could be loaded into viewing software different from the originating software and spot checked. A test plan could be developed for each MAP message and then an OBU used to log paths driven could record movements with the output compared to MAP message geometry.
- If survey crews or point-cloud vendors are used to generate the MAP messages, then subsequent geometry verification can probably be skipped.
- Equipment and software needed for field verification might include:
  - Vehicle OBUs;
  - Vendor-provided management tools;
  - OEMs driving vehicles through the intersections, then providing feedback;
  - GPS units for locating vehicles as they drive through the intersection; and

    - Portable suitcase testers to verify SPaT and MAP messages (available from multiple vendors).
- The simplest field verification might be visual confirmation of centerlines and stop lines consistent with the MAP data interpretation as received by an OBU.
- Field verification might also include decoding the MAP messages received from the RSU to confirm match with the intended maps.

Basis:

- Field validation is needed to confirm that the MAP message conforms to the requirements of the CTI 4501 v01.01, Connected Intersections Implementation Guide.

3.0 Scenarios

This section describes what typically happens in each of the seven steps described above for creating MAP messages for the following five scenarios. Each scenario includes details on what is expected from both the contractor and IOO perspectives.

- Scenario #1: Complete basic MAP message content for a Simple Intersection
- Scenario #2: Description of how Scenario #1 changes for an intersection with channelized turn lanes
- Scenario #3: Description of how Scenario #1 changes for an intersection with a horizontal curve on the approach
- Scenario #4: Description of how Scenario #1 changes for an intersection with pedestrian controls
- Scenario #5: Description of updating a MAP message.

3.1 Scenario #1: Complete Basic MAP Message Content for a Simple Intersection

There are seven steps that can be followed to produce a MAP message. Assembling required information, determining a reference point, and placing lane nodes are necessary to define the geometry of the subject roadway or intersection. Converting the geometric information to a UPER encoded SAE J2735 message and loading that information to roadside equipment are necessary for deployment. Visual and field validation steps are optional but recommended to verify that what the MAP message describes accurately reflects reality.

<u>Step 1 - Assemble Data</u>

Assembling the required information is a valuable first planning step that makes subsequent steps much easier. Key pieces of information include:

- the road regulator and intersection reference identifiers;
- the revision number for the MAP message;
- the extent of the geometry to be represented in the message, including information described below;
- signal phase information;
- Agency agreed intersection numbering scheme; and
- Agency agreed lane numbering scheme.

<u>Step 2 - Determine Verified Point Marker</u>

The next step is to determine a verified point marker. This allows a landmark with an accurately known location to be used as an adjustment to software-projected aerial views. As illustrated in Figure 25, the verified point marker should be a landmark that can be surveyed in the field and also viewed through available aerial images (e.g., an on-line MAP creation tool using aerial imagery).

Note that the guidance of this document recommends using the Verified Point Marker to calculate known coordinates of a reference point that is located inside the intersection (without trying to identify the center of the intersection as the reference point). Placing a reference point inside the intersection minimizes the distance offset to each lane's initial node, but there is unlikely to be a verifiable landmark at that location. In either case, be sure to record the measured geo-coordinates of the verified position and the horizontal and vertical distance between the verified position and reference point.

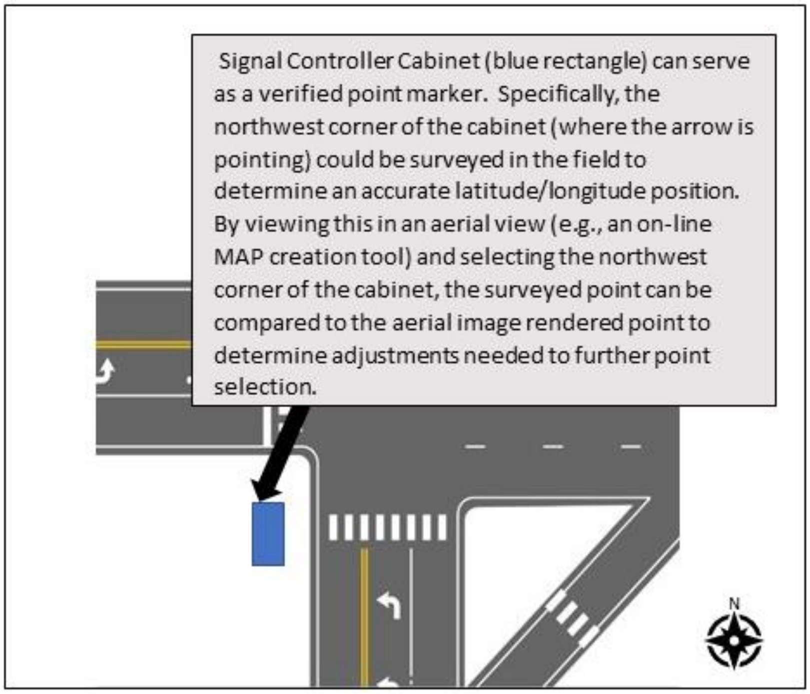


Figure 25: Intersection Reference Point
Source: Synesis Partners

Step 3 - Place Nodes and Create MAP Content

Examples of how to place nodes and describe node attributes.

Nodes define geometrically significant locations along a lane and include lane width change and speed limit attributes. The initial node of a lane is typically placed at the upstream edge of a stop line, the upstream edge of a crosswalk, or before the nearest intersecting lane. Subsequent nodes offsets are calculated moving away from the intersection. Software tools should automatically determine the offsets.

Figure 26 depicts a lane number scheme starting from the southwest lane and proceeding counter-clockwise for the vehicle lanes, followed by crosswalks also starting from the southwest and proceeding counter-clockwise. Ingress lanes are denoted as green circles, egress lanes are denoted as red squares, and crosswalks are denoted by amber triangles. Lanes are required to have at least two nodes, but egress lanes can be kept short.

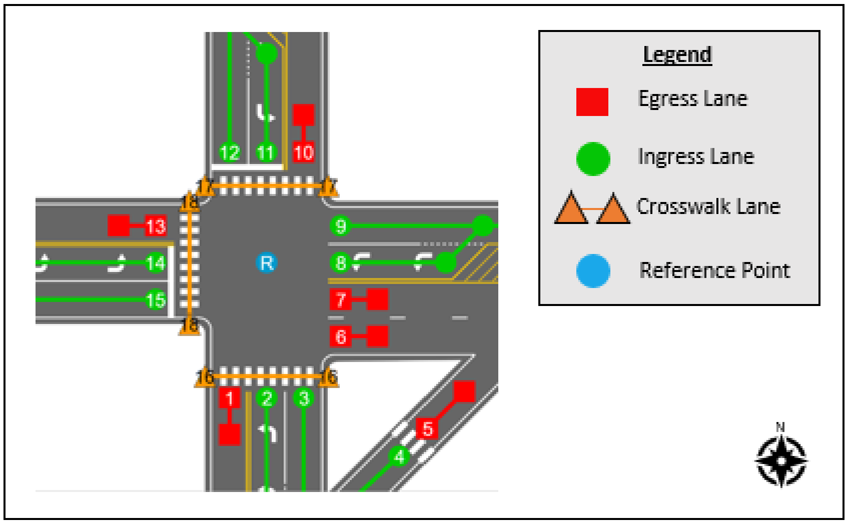


Figure 26: Intersection Lane Numbers
Source: Synesis Partners

Initial node information is recorded as a distance offset from the previously defined reference point, and subsequent nodes are recorded as distance offsets from the previous node in the lane. The maximum offset distance between nodes is 327 meters. Long lane definitions may need multiple nodes even if the lane has no curve. Figure 27 shows the nodes defining the lanes within the example intersection. Most of the lanes contain three nodes, but the ingress lanes from the west need extra nodes to capture the longer curve.

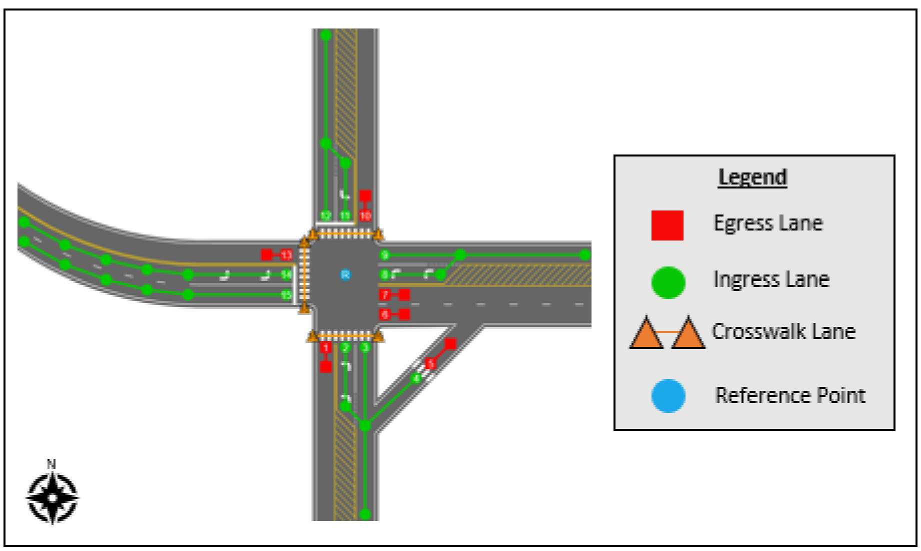


Figure 27: Intersection Lane Nodes
Source: Synesis Partners

Figure 28 focuses on the westbound and northbound ingress lanes to show that there are repeated (same position but separate instance) nodes for lanes 2, 3, and 4; as well as lanes 8 and 9. The repeated nodes (3 times) for lanes 2, 3, and 4 occur at the left-turn and channelized right-turn gore points. The repeated nodes for lanes 8 and 9 occur at the left-turn gore point. The handling of channelized turn lanes is described later in this section.

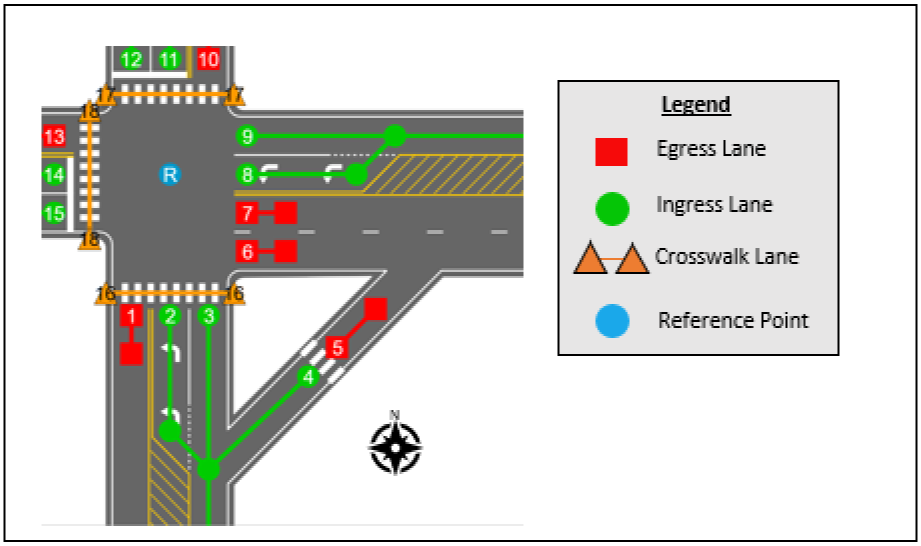


Figure 28: Intersection Repeated Nodes
Source: Synesis Partners

If lane 6 is wider than the other lanes, the initial node for lane 6 would include a "delta value" representing change in width from the default lane width for the intersection. Similarly, if the reference speed limit for the intersection is set to 35 MPH and ingress lanes 2 and 3 have speed limits of 30 MPH, then changes to the initial node attribute for each of those lanes could lower the speed limit. A lane could be simply represented by two nodes, but if lanes contain lane width or speed limit changes between the end points, then internal nodes are added to contain the attributes and apply them to the lane segment. The J2735 standard includes a "speed limit type" data element. The most common speed limit type is "maximum speed". However, other types, such as "Maximum Speed in School Zone When Children are Present" can be used to indicate additional speed limits. As noted earlier, additional nodes would be needed to indicate the start and end of these areas where additional speed limits apply.

Examples of how to define lane attributes

There are lane attributes in addition to node attributes. A lane contains the set of nodes that define the physical lane geometry and also determines the path direction and type of traffic expected. For the example intersection, the ingress lanes have the ingress path attribute set, the egress lanes have the egress path attribute set, and the crosswalks have both the ingress and egress attributes set as they are bi-directional. Additionally, most of the lanes contain the lane type attribute for vehicle traffic, while the crosswalks contain the crosswalk lane type for pedestrian traffic.

Examples of how to link a Signal Phase Diagram with Allowed Movements in the MAP Message

In order for the MAP message to enable application to understand which signal control group is controlling flow in their lane of travel, the MAP developer needs to identify and define attributes for allowable connections from each ingress lane to corresponding egress lanes that represent possible movements through the intersection. To define the connections, the MAP developer must:

- Identify the ingress lane and corresponding egress lane that make up the connection;
- Assign the appropriate signal phase (signal control) and maneuvers to each connection.

Initial Activity: Identifying the ingress lane and corresponding egress lane that make up the connection: First, using the resources gathered in Step 1, the MAP developer should start with an ingress lane and identify all connections to egress lanes. Using illustrations in Figure 29 as an example:

- The MAP developer could first identify all connections that originate from lane 11:
  - Figure 29a illustrates a yellow line connecting lane 11 to lane 10 (a U-turn).
  - Figure 29a also illustrates a yellow line connecting lane 11 to lane 7.

  Collectively these two connections define the possible connections from lane 11.

- Next, the MAP developer could identify all connections that originate from lane 15:
  - Figure 29b illustrates a yellow line connecting lane 15 to lane 7.
  - Figure 29b also illustrates a yellow line connecting lane 15 to lane 6.
  - Figure 29b also illustrates a yellow line connecting lane 15 to lane 1.

  Collectively these three connections define the possible connections from lane 15.

- Next, the MAP developer could identify all connections that originate from lane 2:
  - Figure 29c illustrates a yellow line connecting lane 2 to lane 1.
  - Figure 29c also illustrates a yellow line connecting lane 2 to lane 13.

  Collectively these two connections define the possible connections from lane 15.

A few specific notes about the example illustrated in Figure 29:

- Identifying connections between ingress and egress lanes is relatively straightforward for an intersection with a single lane at each egress, however, can get more complicated for larger, multi-lane intersections. For instance, anytime a single left- or right-turn lane or a through lane connects to an intersection egress with multiple lanes (e.g., lane 15 or lane 11), a separate connection must be created for each egress lane.
- Additionally, even though it may not be apparent in the satellite view of the intersection, a left-turn lane may also be used for U-turns. Unless a U-turn is prohibited at the intersection (e.g., on signage or per local regulations), connections should be created from the appropriate, inner-most left-turn ingress lane to all available egress lanes to represent this movement (e.g., the U-turn defined for lane 11).
- The MAP creation tools will typically have user interfaces that make selection of connecting lanes very easy if the MAP creator has identified all the applicable connections for each lane.

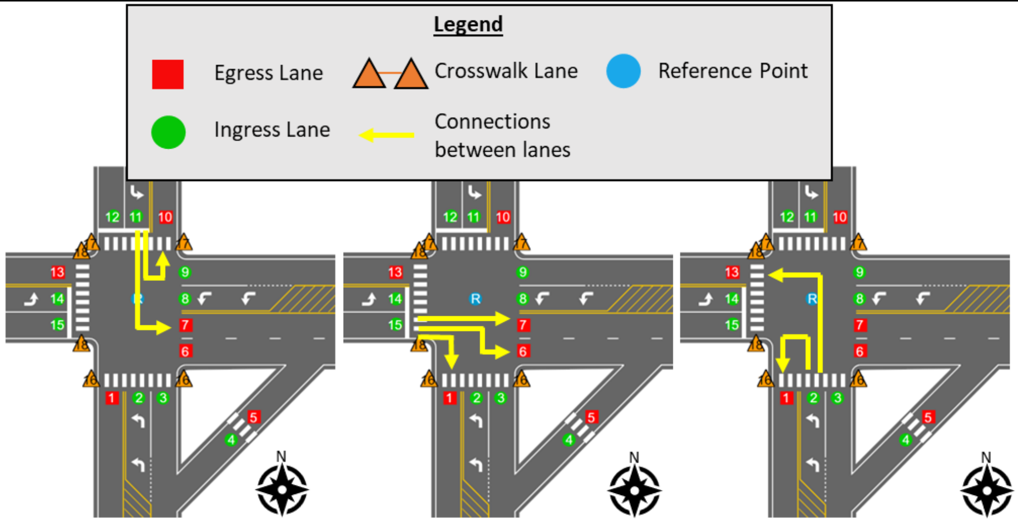


Figure 29a: Illustration of two connections originating at lane 11 for a left-turn to lane 7 and allowable U-turn (to lane 10)

Figure 29b: Illustration of three connections originating at lane 15 (to lanes 1, 6, and 7)

Figure 29c: Illustration of two connections originating at lane 2 (to lanes 1 and 13)

Figure 29: Sample Intersection

Source: Synesis Partners and Athey Creek Consultants

<u>Second Activity: Assigning Signal Phase and Maneuvers to each Connection:</u>

Once all the connections are defined, the MAP developer must then relate these connections to the signal phase diagram for the intersection, which may be like the one shown in Figure 30. In this scenario, the MAP creator had access to the phase diagram shown below and was able to understand each phase. The MAP creator then contacted the traffic engineer responsible for the intersection and was able to verify that Phases 1-8 are represented as signal groups 1-8 in the SPaT message that is output to the RSU. With this information, the MAP creator can assign the signal group to each connection. Similarly, the MAP creator was able to identify the maneuver that is permitted or protected for each connection using the signal phase diagram. For example, using the phase diagram illustrated in Figure 30, the signal groups for previous movements identified above:

- The connection from lane 11 to lane 7 corresponds to Phase 5 and therefore is assigned to Signal Group 5 and has the maneuver “Left allowed”;
- Also, the connection from lane 11 to lane 10 corresponds to Phase 5, is assigned to Signal Group 5 and has the maneuver “U Turn allowed”.
- As another example, the connection from lane 15 to lane 7 corresponds to Phase 8, is assigned to Signal Group 8 and has the maneuver straight allowed.
- Finally, the connection from lane 15 to lane 1 corresponds to Phase 8, is assigned to Signal Group 5 and has the maneuver right allowed.

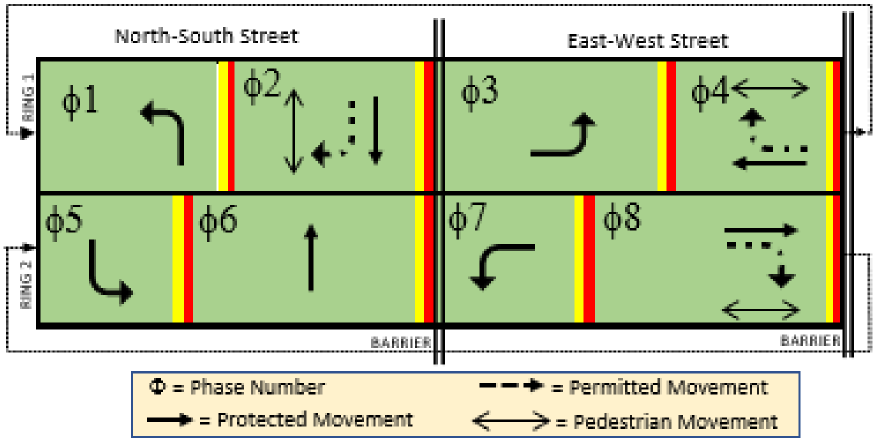


Figure 30: Example Signal Phase Diagram

Source: Athey Creek Consultants

The full list of relationships for connections, corresponding signal group ID, and allowed maneuvers for this representative intersection is shown in Table 8. Note that several ingress lanes have multiple connections to egress lanes, but each connection is assigned to one phase.

Table 8: Relationship of Lanes and Connections to Signal Groups for MAP Message

Connection #	(Ingress) Lane	Connects To (Egress) Lane	Signal Group ID	Allowed Maneuver(s)
1	2[+]	13	1	LeftAllowed
2	2[+]	1	1	UTurnAllowed
3	3	10	6	StraightAllowed
4	4	5	6	yieldAllwaysRequired
5	8	1	7	LeftAllowed
6	8[*+]	6	7	UTurnAllowed
7	8[*+]	7	7	UTurnAllowed
8	9	10	4	RightAllowed
9	9	13	4	StraightAllowed
10	11[*]	6	2	LeftAllowed
11	11[*]	7	2	LeftAllowed
12	11[*]	6	5	LeftAllowed
13	11[*]	7	5	LeftAllowed
14	11[+]	10	5	UTurnAllowed
15	12	1	2	StraightAllowed
16	12	13	2	RightAllowed
17	14	10	3	LeftAllowed
18	14[+]	13	3	UTurnAllowed
19	15	1	8	RightAllowed
20	15[*]	6	8	StraightAllowed
21	15[*]	7	8	StraightAllowed

[*] *For instances where a single left- or right-turn lane or through lane connects to an egress with multiple egress lanes, a separate connection is required to each egress lane.*

[+] *A left-turn lane may also need to include one or more connections to consider U-turns*

[#] *Note whether turning maneuvers are permitted on red*

Table 8 is intended to be comprehensive in detail, however it should be noted that the information presented may not be entered in this manner, depending on what tool is used to create the MAP message. For example, the information for allowed maneuvers may not be entered with a linkage to the egress lane connection, and may be entered as a single entry instead of multiple rows. An example of how allowable maneuvers, signal group ID, and connections to egress lanes for a sample intersection are entered and displayed for a MAP creation tool is shown in Figure 31 for the USDOT Tool.

Figure 31: Interface showing entry of allowed maneuvers, signal group ID, and connections to egress lanes for a sample intersection.

Source: [USDOT ISD Builder Tool]

<u>Step 4 - Visual Validation</u>

Visual validation of the MAP message content is straightforward and cost-effective. If a software application that includes an aerial view is being used, visual validation is continuously available and is part of the MAP message creation. A reviewer could use a different aerial view to get an independent, perspective. Alternatively, a software tool that can read the input format and render the MAP information on an aerial view could be used, as illustrated in Figure 32.

Figure 32: Visual validation confirmation of nodes

Map Source: Google Maps, Source of node points: University of California, Berkeley, PATH

Step 5 - Convert to SAE J2735 Format

The conversion from a human-readable message to an UPER-encoded binary package is not trivial and software tools are needed. A tool used to enter MAP message data and place node points will likely be able to generate the UPER-encoded message. If not, the encoding tool needs to be able to import the format used to define the MAP message in the previous steps. The tool used to encode the message should also perform quality checks against the SAE J2735 specification and report any errors. If no errors are encountered, the tool should optimally encode the MAP message and geometry information in the most compact form possible and produce output that can be saved to an engineering document management system.

Step 6 - Load to RSU

Once the UPER-encoded message has been created, it should be able to be deployed to roadside equipment. This step can be vendor-dependent, so there may be a process to convert the UPER encoded message to the format needed by roadside equipment. Follow vendor instructions for conversions as needed, as well as the instructions for deploying the final MAP message to the equipment.

Step 7 - Field Validation

Now that the created MAP message is deployed, field validation can be performed. Field validation should include confirming that deployed messages are being broadcast, that received MAP message identifiers match those expected, and that the defined geometry agrees with the physical roadway arrangement. The first two checks verify functioning roadside equipment and eliminate possible clerical errors. The geometry check catches construction changes that may not have been available or known at the time MAP information was recorded.

3.2 Scenario #2: Description of how Scenario #1 changes for an intersection with channelized turn lanes

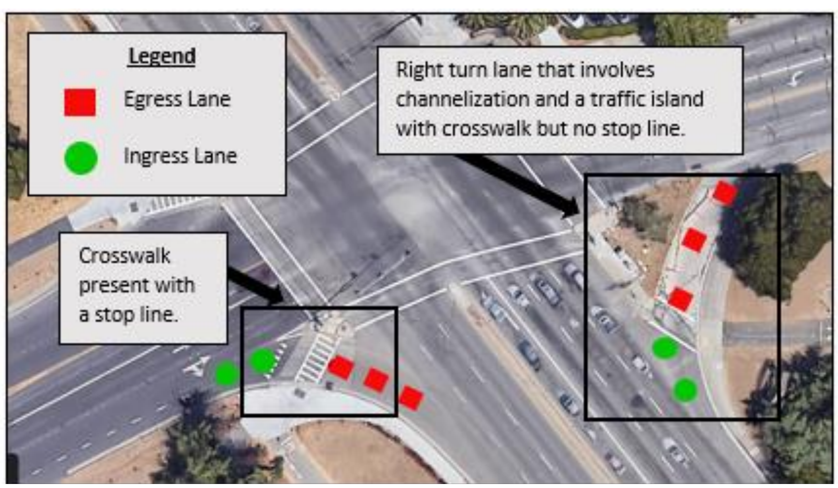


Figure 33: Intervening paths where there are dedicated or channelized turn lanes

Map Source: Google Maps, Drawing source: Athey Creek Consultants

In the case of an intersection where there are dedicated or channelized turn lanes, there can be intervening paths, such as cross walks, bike lanes, or even light rail. When this situation occurs, the lane definition methodology is the same, except that an ingress lane's initial node is placed at the near edge of the intervening path and the initial node of an egress lane is placed at the far edge of the intervening path. Figure 33 depicts an example of this arrangement.

3.3 Scenario #3: Description of how Scenario #1 changes for an intersection with a horizontal curve on the approach

Many roadways and intersections include horizontally curved pavement to accommodate widely varying terrain, geographic features, and adjoining geometries affected by similar influences. When horizontally curved lanes are encountered, typically there is a need for additional ingress node points to maintain the accuracy of the node points in relation to the center of the lane. Guidance #3.16: Node Spacing in Horizontal Curves defines an iterative process that the MAP creator can follow to determine how many nodes are required and to verify when enough nodes have been located. While MAP creation tools make the process of adding additional nodes easy, MAP creators should also try to avoid creating more nodes than are needed, as the size of the MAP file is constrained. See Figure 34.

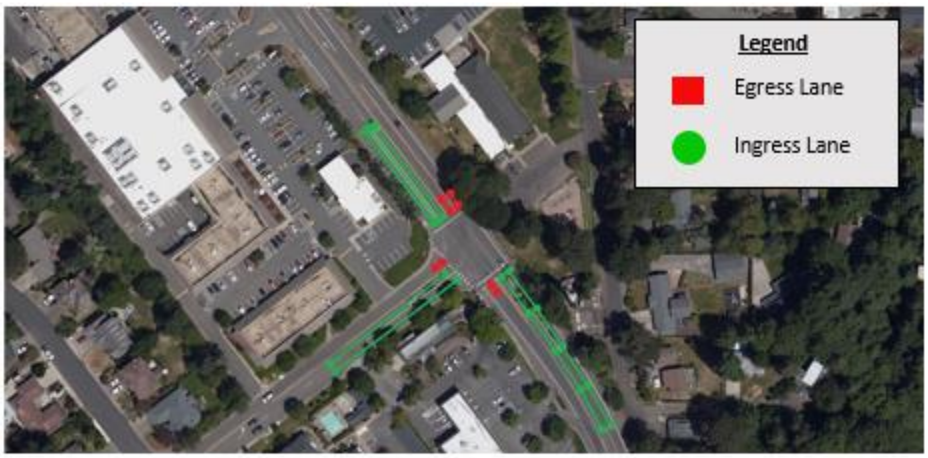


Figure 34: Horizontal curve node spacing

Map Source: Google Maps, Drawing source: Synesis Partners

3.4 Scenario #4: Description of how Scenario #1 changes for an intersection with pedestrian controls

Many intersections include pedestrian controls that can be incorporated into the MAP message to make it more robust for use in a broader set of safety applications. Specifically, sidewalks, crosswalks, and pedestrian signals can be represented in the MAP message as described by this scenario.

First, there are two types of lanes that are used to fully represent pedestrian movements in the MAP message.

- Crosswalk lanes in the MAP message replicate the area marked by painted-striping at the intersection that is designated for pedestrians to cross the road, specifically during pedestrian signal indications (e.g., "walk"). In the MAP message, this area is used by applications to understand potential conflict areas between vehicles and pedestrians.
- Sidewalk lanes defining pedestrian landings are used to describe protected, pedestrian-only locations at or behind the curb where pedestrians will be located before entering a crosswalk lane.

The MAP creator should identify these locations used by pedestrians at the intersection in step 1 to be prepared for creating these lanes in step 3. Specifically, the centerline of striped crosswalk lanes and the width of each crosswalk will be used to create the MAP message. When placing the nodes in step 3, each crosswalk lane will be defined by two coordinates, representing the centerline ends of the crosswalk where the crosswalk meets the curb. Next, sidewalk lane nodes will be placed at the exact same location of the end nodes of the crosswalk lane where it meets the curb. The sidewalk lane nodes will connect all crosswalks at that corner of the intersection.

As illustrated in Figure 35, for example, nodes for crosswalk lane 18 will be located at the same points as a node for sidewalk lane 19 in the bottom left corner of the intersection and a node for sidewalk lane 20 in the top left corner of the intersection. When there is only one crosswalk at a given corner of the intersection, only one node of the sidewalk lane will have the same coordinates as a crosswalk node at the curb. For example, in the top right corner of the intersection in Figure 35, the node for crosswalk lane 17 connects to one node of sidewalk lane 21, while the second node of sidewalk lane 21 is located at the curb and does not connect to any other node (as there is no crosswalk on the right side of the intersection). Note that the nodes for sidewalk and crosswalk lanes in Figure 35 are placed in adjacent locations for illustrative purposes, but for the MAP message should be the same coordinates.

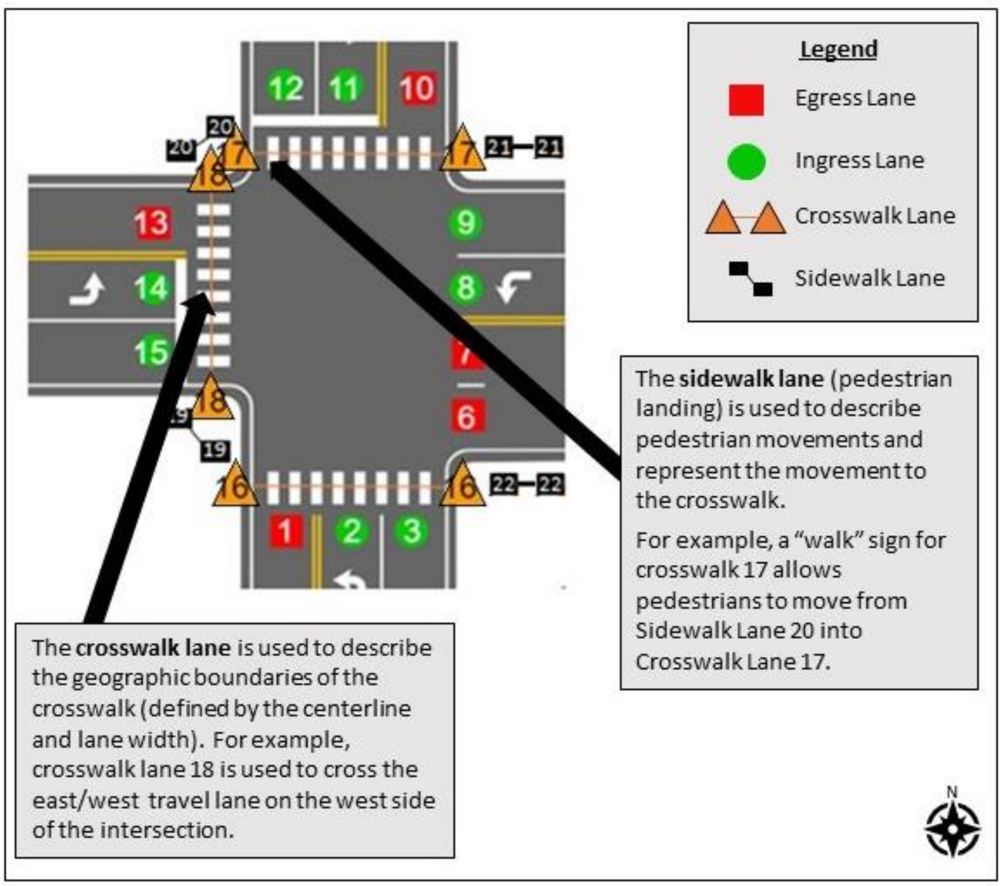


Figure 35: Example of how to place sidewalk and crosswalk lanes

Source: Synesis Partners and Athey Creek Consultants

When making connections, the sidewalk lane always serves as a type of ingress lane and the crosswalk lane as an egress lane for defining pedestrian movements. Connections are made from sidewalk nodes to respective, co-located crosswalk nodes (i.e., the connection does not go from the crosswalk node to the sidewalk node) to denote maneuvers, which are always designated as “straight”, allowed from the sidewalk lane (pedestrian landing) to the crosswalk by a “walk” sign in a signal group. Signal group information for pedestrian movements should be found in signal phase diagrams, such as the one found in Figure 30. For example, the connections from sidewalk lanes 19 and 20 to crosswalk lane 18 correspond to signal group ID 2. The full list of relationships for sidewalk and crosswalk lane connections, corresponding signal group ID, and allowed maneuvers for this representative intersection is shown in Table 9. Note that several ingress lanes have multiple connections to egress lanes, but each connection only is assigned to one phase.

Table 9 is intended to be comprehensive in detail, however it should be noted that the information presented may not be entered in this manner, depending on what tool is used to create the MAP message. For example, the information for allowed maneuvers may not be entered with a linkage to the egress lane connection, and may be entered as a single entry instead of multiple rows.

Table 9: Relationship of Pedestrian Lanes and Connections to Signal Groups for MAP Message

Connection #	(Ingress) Lane	Connects To (Egress) Lane	Signal Group ID	Allowed Maneuver(s)
30	20	17	8	StraightAllowed
31	20	19	2	StraightAllowed
32	21	17	8	StraightAllowed
33	22	18	4	StraightAllowed
34	23	18	4	StraightAllowed
35	23	19	2	StraightAllowed

Note that the visual graphics of a MAP creation tool may be more limited for sidewalk and crosswalk lanes than for motor vehicle ingress and egress lanes, given the nature of connections between two nodes that have the same geographic coordinates. Additionally, some MAP creation tools may not yet have advanced capabilities to recognized a crosswalk lane as bi-directional and may visually display a connection from a sidewalk lane to a node at the opposite side of the intersection. In this case, the MAP creator should double check that the node locations have been entered correctly and disregard the visual inconsistencies.

3.5 Scenario #5: Description of updating a MAP message

There are many reasons that a MAP message may need to be revised. For each of these situations, the MAP message contents should be examined for accuracy and revised, as needed. This scenario attempts to provide some principles and considerations for a MAP creator to follow when revising the MAP message for any reason, such as the following:

- Errors may be identified in the current version of the MAP message. This may be something that is obviously incorrect (e.g., a mis-assigned connection between two nodes), or something less obvious (e.g., improved accuracy of node points).
- Addition or removal of signal phases or signal groups.
- Reassignment of connections to different signal phases or signal groups.

- New applications may be desired that require additional or more precise information in the MAP message.
- Restriping may change the configuration of ingress or egress lanes, location of stop lines, permitted movements (e.g., restrict or allow different turn movements), or add new features that were not present before (e.g., new crosswalks).
- Reconstruction may similarly change the location and presence of features, as well as associated movements that are permitted.
- The earth's plate movements may periodically require adjustments to the node point locations.

The nature of any reconstruction or re-striping effort will vary, which makes it difficult for a MAP creator to follow any one process for revising the MAP message.

This guidance document recommends revising the MAP message as soon as is practical in order to minimize adverse impacts to travelers. For maintenance or construction activities, it is likely impractical for agencies to develop interim MAP messages such that no MAP message may be available for hours or even weeks while the work zone and closures are active. Although the timing for removing and revising a MAP message is ultimately left to the judgement of the practitioner, three key principles for practitioners to bear in mind are:

1. 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. A MAP message containing information that does not match physical conditions and traffic control in the field should no longer be broadcast, even though this will disrupt the functionality of applications at a connected intersection.
3. A revised MAP message containing updated and correct information should be created and broadcast as soon as is practical to restore application functionality (i.e., this is preferred in lieu of broadcasting outdated or incorrect information).

Removing an incorrect MAP message. Ideally, a MAP message with incorrect or outdated information would be replaced with a revised MAP message as soon as an error is discovered or removed before a work zone is initiated. In rare instances, the practitioner may determine that the nature of an identified error is not significant enough to immediately remove the MAP message from being broadcast before a revised MAP message can be developed, thereby allowing applications like transit signal priority to continue operating. However, for safety-critical applications, it more likely that broadcast of a MAP message containing any errors should be immediately stopped. This will prevent applications from functioning until a revised MAP message is available for broadcast.

During maintenance activities, it is recommended that practitioners cease broadcast of MAP messages as soon as traffic control is changed to minimize errors. As such, a MAP message should stop being broadcast as soon as a re-striping or reconstruction project begins as these activities will temporarily restrict and change allowable movements, including lanes that are available for use as ingress lanes or egress lanes, or potentially allowing use of an egress lane as an ingress lane instead or vice versa.

A nationally consistent change management process establishing minimum requirements and expectations for MAP messages during work zones and other “temporary” events, if available, should be used by agencies and practitioners to help streamline and standardize this process.

Creating and broadcasting a revised MAP message. Depending on the nature of identified errors or changes at the intersection, a practitioner may choose to either revise the existing MAP message or create an entirely new MAP message. In either instance, practitioners should ensure that the latest MAP message used at the intersection has been identified and take care to increase both the MAP revision number and intersection geometry counter by one from the previously broadcast MAP message. Practitioners may use the design plans to create a new MAP message before the traffic control changes have been fully implemented in the field via re-striping or reconstruction, for example. Again, however, the recommendation is to not begin broadcasting the revised MAP message until the reconstruction is fully completed. For example, even after major elements of reconstruction are complete, the MAP message may still not fully or accurately represent all features on the roadway until signage and striping have been installed. As an example, a stop line or crosswalk in the MAP message that has not been painted might result in message from an application that could be confusing to a driver.

Validate updated MAP message. In addition to making updates or changes in the new MAP message, the MAP creator must ensure that the MAP revision number and intersection geometry counter have each been increased by one from the previously broadcast MAP message. The MAP creator should also verify that the re-striped or reconstructed roadway in the field matches what is in the generated MAP message, particularly if design drawings were used to generate the MAP message. Finally, after the MAP message has been validated, the MAP creator should store, document, and/or archive the files and information about the current MAP message per agency processes and policies to access as future updates are needed.

Appendix A: MAP Message Data Structure

Table A-1 presents the data elements and data frames and organization, as recommended by both SAE J2735 and this guidance.

Table A-1: MAP Message Data and Organization

MAP Message Data and Organization		Required or Optional	
Data Element (DE) and Data Frame (DF)	**Organized Structure**	**SAE J2735**	**This Guidance**
Message Revision Counter	msgIssueRevision = DE_MsgCount	Required	Required
Intersection Geometry	intersections = DF_IntersectionGeometryList	Optional	Required
Intersection Reference Identifier	id = DF_IntersectionReferenceID	Required	Required
Road Regulator Identifier	region = DE_RoadRegulatorID	Optional	Required
Intersection Identifier	id = DE_IntersectionID	Required	Required
Intersection Revision Counter Increment	revision = DE_MsgCount	Required	Required
Intersection Reference Point	refPoint = DF_Position3D lat = DE_Latitude long = DE_Longitude	Required	Required
Lane Width	laneWidth = DE_LaneWidth	Optional	Required
Speed Limit	speedLimits = DF_SpeedLimitList	Optional	Required
Lane Identifier	laneSet = DF_LaneList laneID = DE_LaneID	Required	Required
Direction of Travel	directionalUse = DE_LaneDirection	Required	Required
Revocable Lanes	sharedWith = DE_LaneSharing	Required	Required
Lane Type	laneType = DF_LaneTypeAttributes	Required	Required
Lane Maneuvers	maneuvers = DE_AllowedManeuvers	Optional	Required
Center of Lane Geometry	nodeList = DF_NodeListXY NodeSetXY = DF_NodeXY	Required	Required
Node Offset from Previous Node	delta = DF_NodeOffsetPointXY	Required	Required
Node Points	node-XY6 = DF_Node-XY-32b x = DE_Offset_B16 y = DE_Offset_B16	Required	Required
Computed Lanes	ComputedLane = DF_ComputedLane referenceLaneId = DE_LaneID offsetXaxis offsetYaxis	Required	Required
Lane Connections	connectsTo = DF_ConnectedToList	Optional	Required
Connection Egress Lane	connectingLane = DF_ConnectingLane lane = DE_LaneID	Required	Required
Connection Maneuvers	maneuvers = DE_AllowedManeuver	Optional	Required
Remote Intersection Reference Identifier	remoteIntersection = DF_IntersectionReferenceID	Optional	Required
Connection Signal Group	signalGroup= DE_SignalGroupID	Optional	Required

References

Antonini, Greg. (2019, August). Smart City Intersection Digitization Update. Franklin County, Ohio.

Connected Transportation Interoperability (CTI) 4001 v01 Roadside Unit (RSU) Standard. (2021). Retrieved October 31, 2022. http://www.ite.org/pub/764FB228-0F6C-BA02-6D7B-16A86B1F8108.

Connected Transportation Interoperability (CTI) 4501 v01.01 Connected Intersections (CI) Implementation Guide. (2022). Retrieved October 31, 2022. https://www.ite.org/ITEORG/assets/File/Standards/CTI 4501v0101.pdf.

Connected Transportation Interoperability (CTI) 4502 v01 Connected Intersections Validation Report. (2022). Retrieved October 31, 2022. https://www.ite.org/pub/?id=59A8D354-F7B1-6A18-6FCC-1CECE6ACDE5B.

Connected Vehicle Pooled Fund Study. (Anticipated 2022). Connected Intersections Guidance Document.

Crash Avoidance Metrics Partners LLC (CAMP). (August 16, 2022). Connected Intersection MAP Data Assessment Supporting Basic Red Light Violation Warning, Version 0.90. Retrieved October 31, 2022. https://www.campllc.org/publications.

CAMP. (n.d.). SPaT/MAP Utility, Version 1.

Cooperative Automated Transportation (CAT) Coalition. (2020). Clarifications for Consistent Implementations (CCI) to Ensure National Interoperability: Connected Signalized Intersections, version 1.9.5. Retrieved March 29, 2021. https://transportationops.org/sites/transops/files/Updated%20Signalized%20Intersection%20CCI%20-%2004242019%20ver%201.9.4.pdf.

Federal Highway Administration (FHWA). (2016, October 31). DSRC Roadside Unit (RSU) Specifications Document v4.1. Retrieved March 29, 2021. https://cflsmartroads.com/projects/CV_Testing/USDOT%20RSU%20Specification%204%201_Final_R1.pdf.

FHWA. (2017, July). Model Inventory of Roadway Elements (MIRE) 2.0. Retrieved March 29, 2021. https://safety.fhwa.dot.gov/rsdp/downloads/fhwasa17048.pdf.

Institute of Transportation Engineers (ITE). (n.d.) Connected Intersections. Accessed March 29, 2021. https://www.ite.org/technical-resources/standards/connected-intersections/.

National Operations Center of Excellence (NOCoE). (2017). SPaT Challenge Verification Document, version 1.2. Accessed March 29, 2021. https://transportationops.org/content/spat-challenge-verification-document.

NOCoE. (2018, March). SPaT Challenge Infrastructure System Model Concept of Operations, Version 1.6. Accessed March 29, 2021. https://transportationops.org/spat-challenge-infrastructure-system-model-concept-operations.

NOCoE. (2018, March). SPaT Challenge Infrastructure System Model Requirements, Version 1.1. Accessed March 29, 2021. https://transportationops.org/spat-challenge-infrastructure-system-model-requirements.

NOCoE. (n.d.). Cooperative Automated Transportation (CAT) Coalition. Accessed March 29, 2021. https://transportationops.org/catcoalition.

SAE International. (2020, July 23). V2X Communications Message Set Dictionary J2735_202007. Accessed March 29, 2021. https://www.sae.org/standards/content/j2735_202007/.

Starr, Ray. (2020, April 9). SPaT V2I Interface for Red Light Violation Warning Concept of Operations. Retrieved March 29, 2021. https://transportationops.org/sites/transops/files/SPaT%20V2I%20Interface%20ConOps%2020200409_circulate.pdf.

Starr, Ray. (2020, April 9). SPaT V2I Interface for Red Light Violation Warning System Requirements Specification. Retrieved March 29, 2021. https://transportationops.org/sites/transops/files/SPaT%20V2I%20Interface%20Requirements%2020200409_circulate.pdf

United States Department of Transportation (USDOT). (2016). ISD Message Creator. Accessed March 29, 2021. https://webapp2.connectedvcs.com/.

V2X Hub MAP and SPaT Planning and Implementation Considerations. Retrieved March 29, 2021. https://usdot-carma.atlassian.net/wiki/download/attachments/174620673/V2X_Hub_MAP_and_SPAT_Guide_4-0.docx?version=1&modificationDate=1568137512608&cacheVersion=1&api=v2&download=true.