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SURFACE VEHICLE RECOMMENDED PRACTICE	CTI 4501™/2	PropDft JAN2026
	Issued	Proposed Draft 2026-01-05

Connected Intersections Implementation Guide - MAP Guidance

RATIONALE

The Connected Intersection (CI) Implementation Guide was developed by engaging a broad community of stakeholders, including but not limited to infrastructure owners/operators, automobile original equipment manufacturers (OEMs) and their suppliers, roadside unit (RSU) manufacturers, and the end users of connected vehicle data and services. The guide was supported by the United States Department of Transportation (USDOT) Intelligent Transportation Systems (ITS) Joint Program Office (JPO). Several associations, such as the American Association of State Highway Transportation Officials (AASHTO), the Institute of Transportation Engineers (ITE), the National Electrical Manufacturers Association (NEMA), and SAE International, contributed to ensuring balanced and effective stakeholder representation and adherence to standards development processes as Standards Development Organizations (SDOs).

The CTI 4501 family of documents are recommended practices developed with the combined effort of stakeholders representing the industry at large including IOOs, Automotive Original Equipment Manufacturers (OEMs), Fleet and Truck operators, safety advocacy groups, multimodal partners, and end users of data and services. Several associations including AASHTO, IEEE 1609 Working Group, ITE, NEMA, and SAE International are involved in ensuring balanced and effective stakeholder representation and adherence to a consensus-based standards development process.

Through collaboration with these stakeholders, the CTI 4501 family addresses ambiguities and gaps identified by early deployers, providing direction on how to generate consistent, interoperable messages for signalized intersections across the United States, especially for automated transportation systems. Building on the USDOT-sponsored Cooperative Automated Transportation Clarifications for Consistent Implementations (CCIs) for Connected Signalized Intersections, these recommended practices focus on harmonizing the messages broadcasted by connected intersections.

This document focuses on requirements and design details for broadcasting MAP messages at connected intersections to complement the SPaT messages broadcasted by connected intersections, and provides practical guidance for configuring MAP broadcasts; leading to interoperability and consistent data exchange across different regions and deployments.

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TABLE OF CONTENTS

DRAFT

DRAFT

1. SCOPE

CTI 4501 defines the key capabilities and interfaces a connected signalized intersection must support to ensure interoperability with vehicles, including production vehicles, for state and local Infrastructure Owner Operators (IOOs). A connected intersection is defined as an infrastructure system that broadcasts SPaT, MAP, and optionally position correction data to vehicles.

The CTI 4501 family of documents define procurement and implementation guidance and the expectations leading to minimum performance requirements for a connected intersection. It is intended to be used by IOOs to provide guidance on how to implement an interoperable connected intersection. For OEMs and other application developers, these recommended practices provide an explanation on what data and connected vehicle messages are being provided from an interoperable connected intersection so safety applications can be developed for production vehicles, with an initial focus on the Red Light Violation Warning (RLVW) application. Although the focus is on the RLVW application, requirements for other V2X applications related to connected intersections, including requirements for traffic signal controllers to generate the SPaT information, are also addressed assuming the connected intersection configuration and messages can support them and no significant effort was needed. The Needs to Requirements Traceability Matrix (NRTM) in CTI 4501, 6.2.3, provides the guidance to IOOs for the procurement of a connected intersection.

Recognizing that some stakeholders require more in-depth guidance on specific aspects of connected intersections, Version 2 of the CI Implementation Guide has been reorganized into a main document and several companion subdocuments. The main document establishes the overarching framework – following a Systems Engineering Process (SEP) – and includes a Concept of Operations (ConOps), System Requirements (Functional Requirements), System Design Details, and a Needs to Requirements Traceability Matrix (NRTM). These elements enable users to identify and procure connected intersection solutions that satisfy their specific needs.

The companion documents elaborate on specialized areas such as SPaT, MAP, security, and testing and validation, providing requirements and design details tailored for those subject areas. Figure 1 depicts the relationships among these subdocuments and other documents that support the implementation of a connected intersection. By separating out these focused topics, the guide more effectively supports Infrastructure Owner Operators (IOOs), OEMs, suppliers, and application developers who need targeted information. Taken together, the main guide and the companion documents ensure that connected intersection deployments align with national standards and support a high level of interoperability, ultimately facilitating safer and more efficient automated transportation systems.

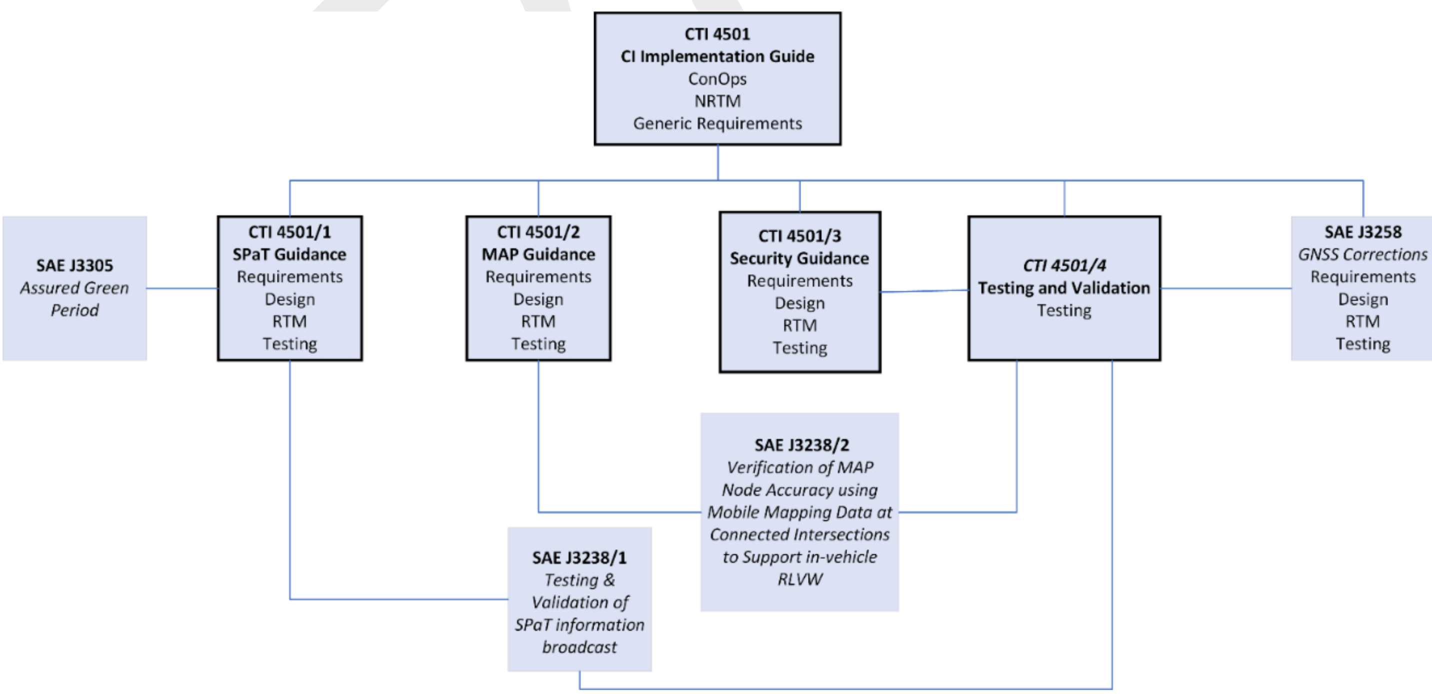

Figure 1 - Relationship with other documents

This MAP Message document offers procurement and implementation guidance specific to MAP messages in one focused resource, while aligning with the overall structure and methodology of the main CTI 4501 document. It provides the requirements, design guidance, and testing considerations necessary to achieve minimum performance requirements for providing MAP messages, tailored for Infrastructure Owner Operators (IOOs), automotive OEMs, and application developers. This document allows stakeholders seeking detailed guidance on MAP-related requirements and design considerations to access all relevant information in one focused resource, while equipping practitioners with a comprehensive set of tools to design and deploy interoperable connected intersections.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE International and other publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J2735	V2X Communications Message Set Dictionary
SAE J2945	Dedicated Short Range Communication (DSRC) Systems Engineering Process Guidance for SAE J2945/X Documents and Common Design Concepts™
SAE J3161	LTE Vehicle-to-Everything (LTE-V2X) Deployment Profiles and Radio Parameters for Single Radio Channel Multi-Service Coexistence
SAE J3161/2	LTE Vehicle-to-Everything (LTE-V2X) Deployment Profiles and Radio Parameters for PC5 Interface in 10 MHz Channel 180
SAE J3258	V2X Infrastructure Support for GNSS Corrections
SAE J3268	Listing of Provider Service Identifiers and Associated Application Technical Reports

2.1.2 Connected Transportation Interoperability (CTI) Publications

CTI documents are jointly developed by American Association of State Highway and Transportation Officials, Institute of Transportation Engineers, National Electrical Manufacturers Association, and SAE International. Available at www.ite.org/technical-resources/standards/connected-intersections.

CTI 4001	Roadside Unit (RSU) Standard
CTI 4501	Connected Intersections (CI) Implementation Guide
CTI 4501/1	Connected Intersections (CI) Implementation Guide - SPaT Messages
CTI 4501/3	Connected Intersections (CI) Implementation Guide - Security
CTI 4501/4	Connected Intersections (CI) Implementation Guide - Testing and Validation

DRAFT

2.1.3 ETSI Publications

Copies of these documents are available online at www.etsi.org.

ETSI TS 136 213 Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures, V14.2.0 (Release 14) [3GPP TS 36.213]

ETSI TS 136 321 Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification, V14.2.1 (Release 14) [3GPP TS 36.321]

ETSI TS 136 322 Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification, V14.1.0 (Release 14) [3GPP TS 36.322]

2.1.4 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

Please note that this report incorporates certain IEEE specifications by reference. ESSENTIAL IPRs (Intellectual Property Rights) have been declared to IEEE. All information statements and licensing declarations of ESSENTIAL IPRs received by IEEE are publicly available via the IEEE IPR Online Database found at https://standards.ieee.org/about/sasb/patcom/patents/.

IEEE Std 802.11 IEEE Standard for Information technology--Telecommunications and information exchange between systems local and metropolitan area networks--Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications (IEEE802dot11-MIB in Annex A.3)

IEEE Std 1609.2 IEEE Standard for Wireless Access in Vehicular Environments - Security Services for Applications and Management Messages

IEEE Std 1609.3 IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Recommended Practice.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J3287 V2X Misbehavior Reporting

SAE J3305 Assured Green Period to Support Red Light Violation Warning

SAE J3315 LTE-V2X Requirements and Deployment Profiles for Aftermarket V2X Devices

2.2.2 CAMP Publications

Available from Crash Avoidance Metrics Partners LLC, Tel: 248-848-9595, www.campllc.org/publications.

Red Light Violation Warning (RLVW) Application Vehicle System, Concept of Operations, Version 2.4, CAMP LLC, V2I-4 Consortium, 1/18/2021.

Red Light Violation Warning (RLVW) Application Vehicle System, High-Level System Requirements, Version 1.10, CAMP LLC, V2I-4 Consortium, 1/12/21.

DRAFT

2.2.3 Connected Transportation Interoperability (CTI) Publications

CTI documents are jointly developed by American Association of State Highway and Transportation Officials, Institute of Transportation Engineers, National Electrical Manufacturers Association, and SAE International. Available at www.ite.org/technical-resources/standards/connected-intersections.

CTI 4502	Connected Intersections Validation Report: Findings from the Connected Intersections (CI) Project Validation Phase.

2.2.4 Connected Vehicle Pooled Fund Study Publications

Copies of these documents are available online at https://engineering.virginia.edu/labs-groups/cvpfs.

CVPFS Connected Intersection Guidance Document

CVPFS CIMMS Systems Requirements, Connected Intersections Message Monitoring Systems Requirements and Prototype Development (CIMMS) Systems Requirements

CVPFS Guidance Document for MAP Message Preparation

2.2.5 ISO Publications

Copies of these documents are available online at www.iso.org/store.

ISO/IEC/IEEE 24765	Systems and software engineering - Vocabulary
ISO 26262	Road vehicles - Functional safety
ISO/PAS 21448	Road vehicles - Safety of the intended functionality

2.2.6 SCMS Manager Publications

Copies of these documents are available online at www.scmsmanager.org/publications.

End-entity Security Requirements, Design Guidance, and Validation Approach

2.2.7 U.S. Department of Transportation Publications

Available from U.S. Department of Transportation, 1200 New Jersey Avenue SE, Washington, DC 20590, Tel: 855-368-4200, www.transportation.gov.

Accelerated Vehicle-to-Infrastructure (V2I) Safety Applications System Requirements Document, FHWA-JPO-13-059, July 18, 2012, https://rosap.ntl.bts.gov/view/dot/26495/dot_26495_DS1.pdf.

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), https://mutcd.fhwa.dot.gov/

RSU Specification 4.1, Dedicated Short-Range Communications Roadside Unit Specifications v4.1, USDOT, Saxton Transportation Operations Laboratory, https://rosap.ntl.bts.gov/view/dot/3600

Systems Engineering for ITS Systems Engineering for ITS, https://ops.fhwa.dot.gov/seits/

2.2.8 U.S. Department of Transportation, National ITS Architecture

Available online at https://www.arc-it.net.

DRAFT

2.2.9 Other Publications

CCI — Cooperative Automated Transportation Clarifications for Consistent Implementations (CCIs) To Ensure National Interoperability Connected Signalized Intersections

CIS Controls Guide — CIS Controls™ Implementation Guide for Industrial Control Systems. Available at https://www.cisecurity.org/white-papers/cis-controls-implementation-guide-for-industrial-control-systems/

Enabling Connected Intersections Concept Paper – Working Draft to Support Discussions of the IOO/OEM Forum SPaT/RLVW Group. Available at https://www.ite.org/ITEORG/assets/File/Standards/Enabling%20Connected%20Intersections%20-%20Concept%20Paper%20ver%202_8%20-%2002242020.pdf.

3. DEFINITIONS

For the purposes of this document, the following definitions shall apply.

APPROACH: All lanes of traffic moving towards an intersection or a midblock location from one direction, including any adjacent parking lane(s). An approach is typically identified by its general flow, i.e., "the east-bound approach." In this document, an approach consists of one or more motor vehicle lanes of travel, as well as possible pedestrian lanes, parking lanes, barriers, and other types of lane objects some of which cross the path of the motor vehicle travel. Approach is also used in certain messages to specify where one or more lanes begin, regardless of whether the lane is ingress or egress. Source: SAE J2735

APPROACH SPEED: The uninterrupted speed (or free-flow speed) of through movement vehicles used in the design of the timing parameters that control the operations of the traffic signal.

ASSURED GREEN PERIOD (AGP): When a connected vehicle is approaching a connected intersection in a through lane currently in a green signal state indication, the AGP is a fixed portion of green interval for the through movement that, when combined with the duration of the yellow change interval, decreases the likelihood that the vehicle will be in the connected intersection during a red signal state indication.

COMPONENT: An element of the CI System. The element may be a device or a logical process.

CONNECTED INTERSECTION (CI): An infrastructure system that creates and broadcasts signal, phase, and timing (SPaT), mapping information, and position correction data to On-Board Units (OBUs) and Mobile Units (MUs).

CONNECTED VEHICLE: A vehicle equipped with devices enabling interoperable direct short-range broadcast communication to convey and receive safety- and mobility-enhancing messages.

CONNECTION: In the context of a connected intersection, the link between an ingress lane and a downstream lane, which may be an egress lane out of the intersection or an ingress lane within the intersection (e.g., storage lane).

EXTERNAL CONTROL LOCAL APPLICATION (ECLA): An application that asserts a higher-level control over the traffic signal controller.

FIRMWARE: Software tightly coupled to a specific piece of computing hardware. Typically used for control, configuration, and interface definition, and rarely interacted with directly by the user. It may be necessary for firmware to be updated from time to time, for example, to ensure the continued correct operation of the hardware or expose or enable new features.

INTERFACE: A shared boundary across which information is passed. Source: IEEE Std 610.12

INTEROPERABILITY: The ability of two or more systems or components to exchange information and to use the information that has been exchanged. Source: IEEE Std 610.12

INTERSECTION or INTERSECTION BOX: Where a stop line, yield line, or crosswalk is designated on the roadway on the intersection approach, the area within the crosswalk and/or beyond the designated stop line or yield line shall be part of the intersection. If there are no stop lines, then the intersection box is defined by the extension of the curb lines. Refer to MUTCD for additional definitions of an intersection.

LONG TERM EVOLUTION–BASED VEHICLE-TO-EVERYTHING (LTE-V2X): Vehicle-to-everything (V2X) sidelink communications protocols specified by 3GPP (releases 14 and 15).

MOBILE UNIT (MU): A device used to wirelessly communicate with other devices for safety and mobility purposes carried by a pedestrian, bicyclist, work zone worker, or other traveler. Source: CTI 4001

MOVEMENT: A term used to describe the user (e.g., vehicle or pedestrian) action taken at an intersection (e.g., vehicle turning movement or pedestrian crossing). Two different types of movements include those that have the right-of-way (protected/exclusive) and those that must yield (permitted/permissive), consistent with the rules of the road or the Uniform Vehicle Code. Source: Signal Timing Manual

ON-BOARD UNITS (OBU): A device used to wirelessly communicate with other devices for safety and mobility purposes installed in a vehicle as original equipment or as aftermarket equipment (sometimes referred to as an "aftermarket V2X device" [AVD]). Source: SAE J3315

PERMISSIVE MOVEMENT: A permitted movement that may conflict with protected movements and other permissive movements. Traffic making a permissive movement must yield to conflicting traffic and may be required to first come to a full stop.

PERMITTED MOVEMENT: A movement that is allowed to proceed if there are available gaps in the conflicting flow. Source: Signal Timing Manual

POSTED SPEED LIMIT: A speed limit determined by law or regulation and displayed on Speed Limit signs. Source: MUTCD

PROTECTED MOVEMENT: A permitted movement that has the right of way and may conflict with permissive movements. Traffic making a protected movement must watch for conflicting traffic.

PROVIDER SERVICE IDENTIFIER: An integer which identifies an application specification. Source: SAE J3268

RED LIGHT VIOLATION WARNING (RLVW) APPLICATION: An in-vehicle application intended to influence drivers approaching the intersection that are either unintentionally not stopping at red lights or would not pass the intersection before the red interval begins, both of which could lead to conflicts with cross-traffic. Source: RLVW Application Vehicle System, Concept of Operations

REGULATORY SPEED LIMIT: A speed limit established by the IOO and that is not necessarily displayed on Speed Limit signs.

ROADSIDE UNIT (RSU): A transportation infrastructure communications device located on the roadside that provides V2X connectivity between OBUs/MUs and other parts of the transportation infrastructure including traffic control devices, traffic management systems, and back-office systems. Note: Devices that are not part of the transportation infrastructure, such as cellular base stations or satellites, are not RSUs. Source: CTI 4001

ROBUSTNESS: Degree to which a system or component can function correctly in the presence of invalid inputs or stressful environmental conditions. Source: ISO/IEC/IEEE 24765

REVOCABLE LANE: A lane whose properties may be in effect or not. Lane properties in SAE J2735 are defined by the type of lane (e.g., a travel lane, a parking lane, a shoulder), the type of travelers that may use the lane (passenger vehicles, transit vehicles only, bicycles, pedestrians), and the direction of travel. A physical lane in the roadway may be defined by more than one lane identifier, each with a different set of lane properties, and a bit can be used to determine if that lane property is in effect or not. For example, a reversible lane may be defined by two lane identifiers, one for each direction of traffic, but only one (revocable) lane identifier is in effect.

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SIGNAL GROUP: A logical grouping of one or more traffic movements that are controlled by the same traffic signal indication (e.g., green, yellow, red). Each signal group typically governs the right-of-way for a specific set of vehicle or pedestrian movements at an intersection and is the basis for how signal timing is communicated in connected vehicle systems. Signal groups enable coordination between the SPaT and MAP messages by identifying which movements receive which signal indications. See MOVEMENT. Source: SAE J2735, section on DF_MovementState

SIGNAL GROUP ID: A numeric identifier assigned to a signal group within the Signal Phase and Timing (SPaT) message. It uniquely identifies which set of traffic movements are governed by a particular signal indication at a given intersection. This ID serves as the link between the SPaT message (which provides the signal state) and the MAP message (which defines the intersection's geometry and permitted movements). See MOVEMENT. Source: SAE J2735, section on DF_MovementState

SIGNAL INDICATION: The illumination of a signal lens or equivalent device. Source: MUTCD

SIGNAL TIMING DATA: For the purpose of this document, signal timing data for a CI is the movement state and information when a movement may end for each movement at an intersection.

SPaT INFORMATION: Signal phase and timing data, such as timing and movement state information for each movement through an intersection, which is sent from a traffic signal controller to another device. This document describes three methods to send SPaT information to RSUs.

STATUTORY SPEED LIMIT: A speed limit established by legislative action (such as Federal or State law) that typically is applicable for a particular class of highways with specified design, functional, jurisdictional, and/or location characteristics and that is not necessarily displayed on Speed Limit signs. Source: MUTCD

THROUGH MOVEMENT: A movement of a vehicle or pedestrian at an intersection where the direction of travel is unaltered by a left-, right-, or U-turn.

TRAVEL LANE: The area of the roadway designated for the movement of a vehicle, pedestrian, bicycle, or designated user.

TSC INFRASTRUCTURE: The systems and components within the transportation field cabinet that control the operations of the signal indications at a signalized intersection, including an external control local application (ECLA) that may assert a higher-level control over the traffic controller.

V2X VEHICLE: A vehicle equipped with devices enabling interoperable direct short-range broadcast communication using 3GPP-defined LTE-V2X Rel-14 PC5 mode to convey safety- and mobility-enhancing messages. The V2X vehicle defined and used in these documents do not include networked communications or commercial connected vehicle applications. Source: SAE J3161 and SAE J3161/1

4. ABBREVIATIONS

Cited below are the abbreviations that are used in this report.

AASHTO	American Association of State Highway and Transportation Officials
AGP	Assured Green Period
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
CCI	Clarifications for Consistent Implementations (document)
CI	Connected Intersection
ConOps	Concept of Operations
CRL	Certificate Revocation List

CV	Connected Vehicle
CVPFS	Connected Vehicle Pooled Fund Study
DSRC	Dedicated Short Range Communication
ECLA	External Control Local Application
FHWA	Federal Highway Administration
FO	Functional Object
GNSS	Global Navigation Satellite System
IEEE	Institute of Electrical and Electronics Engineers
IOO	Infrastructure Owner/Operator
ITE	Institute of Transportation Engineers
JSON	Java Script Object Notation
LTE-V2X	Long-Term Evolution Vehicle-to-Everything
MU	Mobile Units
MUTCD	Manual of Uniform Traffic Control Devices
NEMA	National Electrical Manufacturers Association
NRTM	Needs to Requirements Traceability Matrix
OBU	On-Board Units
OEM	Original Equipment Manufacturers
PDB	Package Delay Budget
PPPP	ProSe per packet priority
ProSe	Proximity Services
PSID	Provider Service Identifier
RLVW	Red Light Violation Warning
RSRP	Reference Signal Receive Power
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
RTCTM	Requirements to Test Case Traceability Matrix
RTM	Requirements Traceability Matrix

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SAE SAE International

SCMS Security Credential Management System

SDO Standards Development Organization

SEP Systems Engineering Process

SPaT Signal Phase and Timing

TSC Traffic Signal Controller

USDOT United States Department of Transportation

V2I Vehicle-to-Infrastructure

V2X Vehicle-to-Everything

5. CONCEPT OF OPERATIONS

Refer to CTI 4501 Section 5, Concept of Operations, for the user needs, Needs to Requirements Traceability Matrix (NRTM), and operational scenarios.

6. FUNCTIONAL REQUIREMENTS

This section defines the functional requirements for MAP messages based on the user needs identified in the Concept of Operations (refer to CTI 4501 Section 5, Concept of Operations). This section includes the following:

a. A tutorial.

b. Needs to Requirements Traceability Matrix (NRTM): A Functional Requirement is a requirement of a given function and therefore is only required to be implemented if the associated functionality (e.g., user need) is selected through the use of the NRTM. The NRTM also indicates which of the items are mandatory, conditional, or optional. The NRTM can be used by procurement personnel to specify the desired features for a connected intersection or can be used by an implementation to document the features supported by their implementation. The NRTM can also be used to define which requirements are to tested (by demonstrating which requirements to be implemented).

c. Requirements: These are requirements that collectively satisfy the user needs related to broadcasting MAP messages in CTI 4501, 5.4, Needs. These requirements provide the details so that user needs can be satisfied and validated.

Section 6 is intended for all readers, including the following:

a. Transportation Managers

b. Transportation Operators

c. Transportation Engineers

d. System Integrators

e. Device Manufacturers

f. Application Developers

For the first four categories of readers, Section 6 is useful in understanding the details of CTI 4501. For these readers, CTI 4501, 6.2.3, NRTM Table, is particularly useful in preparing procurement specifications and assists in mapping the various rows of this table to the more detailed text contained within the other sections.

For the next two categories of readers, this section is useful to fully understand what is required for conformance to CTI 4501. Table 5 in CTI 4501, 6.2.3, may be used to document the capabilities of their implementations.

For application developers, this section is useful to understand the data provided by a connected intersection and what the data represents.

6.1 Tutorial [Informative]

This Functional Requirements section defines the formal requirements that are intended to satisfy the user needs identified in CTI 4501, 5.4, Needs. This is achieved through the development of an NRTM that traces each user need to one or more requirements defined in this section. The details of each requirement are then presented following the NRTM.

6.2 Needs to Requirements Traceability Matrix (NRTM)

Refer to CTI 4501 Table 5, Needs to Requirements Traceability Matrix.

6.3 Requirements

The requirements for a connected intersection to support a RLVW application and specifically for MAP messages follow. Each requirement in this section is found in CTI 4501 Table 5, Needs to Requirements Traceability Matrix.

There are two types of requirements in this document: requirements that apply specifically to MAP messages and requirements to support the broadcast of MAP messages. Direct traceability to requirements in CTI 4501/2 is a characteristic of the former type of requirements, i.e., CTI 4501 Table 5, Needs to Requirements Traceability Matrix, points directly to the requirement in CTI 4501/2. For example, user need 5.4.3.4.1, Intersection Geometry, traces to requirement CTI 4501/2, 6.3.3.4.1.1, Intersection Geometry Information in the NRTM.

Examples of the latter type of requirements are architectural requirements and security requirements – these requirements are necessary to support the broadcast of MAP messages at a connected intersection, but are not requirements on the MAP messages themselves. Most of these requirements are generic requirements for a CI system and this section references those requirements in CTI 4501 or CTI 4501/3.

There are also four requirements that apply to consistency between the SPaT and MAP messages for a specific intersection. Since those requirements are applicable only when a SPaT message is broadcasted, the descriptions of those requirements are found in CTI 4501/1 but are referenced in this section.

Some requirements are not applicable to MAP messages (and are marked as Not Applicable), but the requirements headings are included in this section so the numbering is consistent among CTI 4501 and the companion documents of CTI 4501/2 (e.g., CTI 4501/1).

6.3.1 Architectural Requirements

The requirements for wireless communications from a connected intersection to the applications on an OBU/MU follow.

6.3.1.1 LTE-V2X Traffic Class Settings

Refer to CTI 4501, 6.3.1.1, LTE-V2X Traffic Class Settings.

6.3.1.1.1 Traffic Class Requirements

Refer to CTI 4501, 6.3.1.1.1, Traffic Class Requirements.

6.3.1.1.1.1 ProSe Per Packet Priority - SPaT Message

Not Applicable.

6.3.1.1.1.2 ProSe Per Packet Priority - MAP Message

A connected intersection shall broadcast MAP messages using the SAE J3161 settings specified in Table 1.

Table 1 - MAP LTE-V2X settings

Parameter	Setting	Notes
Frequency Band	Refer to SAE J3161	SAE J3161 only defines a single frequency band.
Destination Layer 2 ID	Refer to SAE J3161	See section on Broadcast Addressing.
Traffic Family	Critical I2V	Refer to section on Different Traffic Classes in SAE J3161.
ProSe per Packet Priority (PPPP) Value	3	This is the minimum value provided by SAE J3161.
Packet Delay Budget (PDB)	100 ms	This is the minimum value provided by SAE J3161.
Channel Occupancy Ratio (CR) Limit	Refer to SAE J3161	
Reference Signal Receive Power (RSRP)	Refer to SAE J3161	
Transmit Power Level	Refer to SAE J3161	• SAE J3161 defines the maximum conducted power at the radio device's port to the antenna cable. • If an implementation needs more power than this, it can do so via the use of a higher gain antenna if the max EIRP is within regulatory requirements. • An implementation may use a lower power level than this as long as if it can still meet the transmit range requirements specific to the implementation.

Note: These settings are the recommended traffic class settings in SAE J3161 for MAP messages.

6.3.1.1.2 Transmit Radio Requirements

The transmit radio requirements for wireless communications using LTE-V2X from a connected intersection to the applications on an OBU/MU follow.

6.3.1.1.2.1 Transmit Radio - SPaT Message

Not Applicable.

6.3.1.1.2.2 Transmit Radio - MAP Message

A connected intersection shall follow the radio profile and parameters for transmitting MAP messages as described in SAE J3161.

6.3.2 TSC Infrastructure to RSU Requirements

Not Applicable.

6.3.3 Message Requirements

The requirements for a connected intersection broadcasting messages to OBUs/MUs follow.

6.3.3.1 Message Performance Requirements

The performance requirements for a connected intersection broadcasting messages to OBUs/MUs follow.

6.3.3.1.1 Uniform Message Requirements

The requirements to provide a consistent representation of the situation and operating conditions at a connected intersection follow.

6.3.3.1.1.1 SPaT Message - SAE J2735

Not Applicable.

6.3.3.1.1.2 SPaT Message - Mandatory Data Elements

Not Applicable.

6.3.3.1.1.3 SPaT Message - Required Data Elements

Not Applicable.

6.3.3.1.1.4 SPaT Message PSID

Not Applicable.

6.3.3.1.1.5 MAP Message - SAE J2735

A connected intersection shall transmit roadway geometry information using MAP messages that conform to SAE J2735 (MSG_MapData).

6.3.3.1.1.6 MAP Message - Mandatory Data Elements

A connected intersection shall provide those data elements in the SAE J2735 MSG_MapData that are defined as mandatory.

6.3.3.1.1.7 MAP Message - Required Data Elements

A connected intersection shall provide those data elements in the SAE J2735 MSG_MapData that are defined as optional but necessary to fulfill the CI requirements, as indicated in the NRTM (refer to CTI 4501 Table 5).

6.3.3.1.1.8 MAP Message PSID

A connected intersection shall broadcast MAP messages using a Provider Service Identifier (PSID) of 0x20-40-97 (0pE0-00-00-17).

The IEEE PSID Public Listing can be found at https://standards.ieee.org/products-programs/regauth/psid/public/.

6.3.3.1.2 Robustness Requirements

Not Applicable.

6.3.3.1.3 Concise Messages Requirements

The requirements to provide complete data describing the situation within the maximum message size supported by the communications stack follow.

6.3.3.1.3.1 Transport Message Size - WAVE

Refer to CTI 4501, 6.3.3.1.3.1, Transport Message Size - WAVE.

6.3.3.1.3.2 Concise MAP Message Requirements

The requirements for concise MAP messages follow.

6.3.3.1.3.2.1 Nodes by Offsets

A connected intersection shall define the location of a node describing the center of a lane at the intersection using offsets from a reference point or a previous node point.

6.3.3.1.3.2.2 Computed Lanes Requirements

The requirements for a computed lane follow. The attributes of a computed lane can be expressed by the attributes of a lane by translating the attributes of another lane at the intersection. The new lane is expressed as an offset from the first point of the referenced lane. These requirements reduce the bandwidth needed to define the new lane at the intersection; instead of transmitting a new sequence of offset values for a lane with the same attributes, only offset values and the lane number of the referenced lane is transmitted.

6.3.3.1.3.2.2.1 Computed Lane - Lane Identifier

A connected intersection shall provide the lane identifier of the referenced lane that a computed lane is based on. The attributes of the computed lane are based on the attributes of the referenced lane.

6.3.3.1.3.2.2.2 Computed Lane - X-Offset

A connected intersection shall provide the x-offset, in centimeters, between the first node point of the referenced lane and the first node point of the computed lane.

6.3.3.1.3.2.2.3 Computed Lane - Y-Offset

A connected intersection shall provide the y-offset, in centimeters, between the first node point of the referenced lane and the first node point of the computed lane.

6.3.3.1.3.2.2.4 Computed Lane - Angle

A connected intersection shall provide the angle of a computed lane relative to the first node point of the referenced lane.

6.3.3.1.4 Advanced Notification Requirements

Refer to CTI 4501, 6.3.3.1.4, Advanced Notification Requirements.

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6.3.3.1.5 Timeliness Requirements

The requirements for indicating changes in the signal indication state and timing follow.

6.3.3.1.5.1 SPaT Message - Broadcast Latency and Accuracy

Not Applicable.

6.3.3.1.5.2 SPaT Message - Broadcast Periodicity

Not Applicable.

6.3.3.1.5.3 MAP Message - Broadcast Periodicity

A connected intersection shall broadcast MAP messages one time per second ±25 ms where the duration of any 10 consecutive messages is 10 seconds ± 25 ms.

6.3.3.1.6 Quality Assurance Requirements

The requirements to provide quality information follow.

6.3.3.1.6.1 Completeness - SPaT Message

Not Applicable.

6.3.3.1.6.2 Completeness - MAP Message

A connected intersection shall provide a MAP message describing all travel lanes where a movement traversing the intersection is permitted.

6.3.3.1.6.3 SPaT Message - Time Mark Accuracy

Not Applicable.

6.3.3.2 Generic Message Requirements

The requirements for a connected intersection transmitting data follow.

6.3.3.2.1 Time Accuracy

Not Applicable.

6.3.3.2.2 Message Revision Requirements

The requirements for messages that have changed since the previous transmission follow.

6.3.3.2.2.1 SPaT Message - Revision Counter Increment

Not Applicable.

6.3.3.2.2.2 SPaT Message - Revision Counter Not Increment

Not Applicable.

6.3.3.2.2.3 MAP Message - Revision Counter Increment

A connected intersection shall increment a revision counter if the value of any data element in the MAP message other than the timestamp changes.

NOTE: There is no requirement for a timestamp in a MAP message in CTI 4501 or CTI 4501/2. A timestamp is an optional data element for a MAP message in SAE J2735.

6.3.3.2.2.4 MAP Message - Revision Counter Not Increment

A connected intersection shall not increment a message counter if the value of no data element in the MAP message other than the timestamp changes.

NOTE: There is no requirement for a timestamp in a MAP message in CTI 4501 or CTI 4501/2. A timestamp is an optional data element for a MAP message in SAE J2735.

6.3.3.2.2.5 MAP Message - Intersection Revision Counter Increment

A connected intersection shall increment a revision counter for the intersection description within a MAP message whenever any data element describing that intersection changes.

Since a MAP message may contain descriptions of more than one intersection, it is possible for the MAP message revision counter to increment but the intersection revision counter to not increment. This happens when a different intersection description in the MAP message changes but not this intersection description.

6.3.3.2.2.6 MAP Message - Intersection Revision Counter Not Increment

A connected intersection shall not increment a revision counter for an intersection description within a MAP message if no data element describing the intersection changes, other than the change in UTC time.

NOTE: There is no requirement for a timestamp in a MAP message in CTI 4501 or CTI 4501/2. A timestamp is an optional data element for a MAP message in SAE J2735.

6.3.3.2.2.7 RTCMcorrections Message - Sequence Number Increment

Not Applicable.

6.3.3.2.3 Timestamp Requirements

Not Applicable.

6.3.3.3 Signal Timing Data Requirements

Not Applicable.

6.3.3.4 Roadway Geometry Data Requirements

The requirements to provide information about travel lanes follow.

6.3.3.4.1 Intersection Geometry Requirements

The requirements to provide information about the lanes in and around an intersection follow.

6.3.3.4.1.1 Intersection Geometry Information

As part of the roadway geometry information, a connected intersection shall contain travel lane information for one or more intersections.

6.3.3.4.1.2 Intersection Geometry - Road Authority Identifier

As part of the roadway geometry information, a connected intersection shall provide a road authority identifier, if an identifier is assigned. The road authority identifier establishes an organization that either owns or operates a connected intersection that is not the same organization that owns or requested the IEEE Std. 1609.2 security certificate used to secure the connected intersection.

NOTE: This requirement is updated in CTI 4501 v02 to replace the road regulator identifier. The updated guidance is that the combination of the OpOrgID (Operator Organization Identifier) in the IEEE Std. 1609.2 certificate, which identifies the organization that owns or requested the certificate, and the intersection identifier should be a globally unique identifier for the connection intersection. The Road Authority Identifier is used to further partition the OpOrgID into an agency or division. Refer to CTI 4501 Section A.1 for a detailed description. SAE J2735_202211 added DE_RoadAuthorityID as a more extensible means of identifying IOOs. There is no data element in SAE J2735 to identify (or exchange) OpOrgID.

6.3.3.4.1.3 Intersection Geometry - Intersection Identifier

As part of the roadway geometry information, a connected intersection shall provide an intersection identifier unique to a roadway authority.

NOTE: This requirement is updated in CTI 4501 v02 to replace the road regulator identifier. The updated guidance is that the combination of the OpOrgID (Operator Organization Identifier), the intersection identifier, and optionally the Road Authority Identifier should be a globally unique identifier for the connection intersection. Refer to CTI 4501 Section A.1 for a detailed description.

6.3.3.4.1.4 Intersection Reference Point Requirements

The requirements for the location of an intersection reference point follow.

6.3.3.4.1.4.1 Intersection Reference Point - Position

A connection intersection shall select an intersection reference point located close enough to the first node point of all lanes associated with the intersection such that the offset can be represented using the DE_Offset_B16 in SAE J2735 (327.67 m).

6.3.3.4.1.4.2 Intersection Reference Point - Description

A connected intersection shall contain the following information regarding an intersection reference point.

a. Latitude, in 1/10th microdegrees, as defined by DE_Latitude in SAE J2735

b. Longitude, in 1/10th microdegrees, as defined by DE_Longitude in SAE J2735

c. Elevation in 10 cm units as defined by DE_Elevation in SAE J2735

6.3.3.4.1.5 Default Lane Width

A connected intersection shall define the default lane width, in centimeters, for all lanes associated with the intersection within ±20 cm. The lane width is the perpendicular distance between the center of the lane markers as defined in CVPFS Guidance Document for MAP Message Preparation.

6.3.3.4.1.6 Lane Identifier

A connected intersection shall assign a lane identifier unique within the intersection for each lane at the intersection, as defined by DE_LaneID in SAE J2735.

6.3.3.4.1.7 Center of Vehicle Lane Geometry

A connected intersection shall describe the geometry of the center of each vehicle lane approaching (ingress), departing (egress) and internal to (storage) the intersection within ±20 cm perpendicular to the lane centerline on the horizontal plane and ±20 cm in elevation. The lane center is the midpoint of a straight line perpendicular to the lane markers (lines) from the center to the center of the lane markers.

NOTE: A value of ±20 cm was selected based on past research and experience. This value may change in future revisions of this report if further studies show a different value is more appropriate.

6.3.3.4.1.8 Center of Crosswalk Geometry

A connected intersection shall describe the geometry of the center of each crosswalk at the intersection with an accuracy of ±20 cm. The crosswalk center is the midpoint of a straight line perpendicular to the crosswalk markers (lines) from the center to the center of the crosswalk markers.

6.3.3.4.1.9 Center of Pedestrian Landings Geometry

A connected intersection shall describe the geometry of the center of each pedestrian landing at the intersection with an accuracy of ±20 cm.

6.3.3.4.1.10 Lane Description

A connected intersection shall describe the geometry of the center of each lane by identifying at least two node points that define at least one line segment depicting the center of the lane.

6.3.3.4.1.11 First Node Point - Ingress Vehicle Lane

A connected intersection shall describe the first node point at the upstream edge of the stop line on the lane centerline of each ingress vehicle lane within ±20 cm perpendicular to the lane centerline and ±20 cm along the lane centerline at the upstream edge of the stop line, with each subsequent node being farther from the intersection.

NOTE: A value of ±20 cm was selected based on past research and experience. This value may change in future revisions of this report if further studies show a different value is more appropriate.

6.3.3.4.1.12 First Node Point - Egress Vehicle Lane

A connected intersection shall describe the first node point at the downstream edge of the crosswalk on the lane centerline for each egress vehicle lane within ±20 cm perpendicular to the lane in the direction of the centerline, with each subsequent node being farther from the intersection.

6.3.3.4.1.13 Node Offset from Intersection Reference Point

A connected intersection shall describe the location of first node point of a lane by providing an X (east-west) and a Y (north-south) offset, in centimeters, from the intersection reference point.

6.3.3.4.1.14 Node Elevation Offset from Intersection Reference Point

A connected intersection shall describe the elevation offset, in 1 cm units, of the first node point of a lane from the intersection reference point.

6.3.3.4.1.15 Offset from Previous Node

A connected intersection shall describe the location of a node subsequent to the first node point of a lane by providing an X (east-west) and a Y (north-south) offset, in centimeters, from the previous node point.

6.3.3.4.1.16 Elevation Offset from Previous Node

A connected intersection shall describe the elevation offset, in 1 cm units, of a node from the previous node point for a lane.

6.3.3.4.1.17 Advanced Notification - Ingress Vehicle Lane

A connected intersection shall describe node points of each ingress vehicle lane that extend a minimum distance upstream from the first node point of the lane 10 seconds at the 85th percentile speed. If this method cannot be used, then the speed used should be equal to, in order of precedence, the posted speed limit; the regulatory speed limit; or the statutory speed limit plus 7 miles per hour (mph).

NOTE: The CVPFS Guidance Document for MAP Preparation indicates that ingress lanes should not cross upstream intersections.

6.3.3.4.1.18 End Nodes - Crosswalk Lane

A connected intersection shall describe the first and last node point of a crosswalk lane at the edge of the curb with the node position described with an accuracy of ±20 cm of the actual node location.

6.3.3.4.1.19 End Nodes - Pedestrian Landing

A connected intersection shall describe the first and last node point of a pedestrian landing (essentially a sidewalk lane) at the edge of the curb, co-incident with the end nodes of the adjacent crosswalk lanes with the node position described with an accuracy of ±20 cm of the actual node location.

6.3.3.4.1.20 Maximum Distance between Nodes

When describing a lane, a connected intersection shall place the next node point within a distance such that the maximum distance between the actual centerline of a lane and a straight line between the two node points is not greater than 50 cm. This concept is shown in Figure 2.

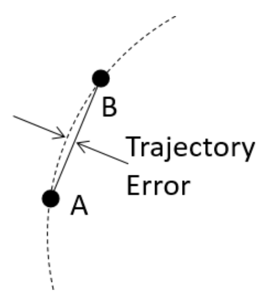

Figure 2 - Trajectory error

6.3.3.4.1.21 Maximum Number of Nodes

A connected intersection shall describe the centerline of the path of a lane with no more than 63 node points.

6.3.3.4.1.22 Node Lane Width

If the width of a lane at a node point is different than the default lane width, a connected intersection shall describe the change in width of the lane, in centimeters, at the node position, with an accuracy of ±20 cm of the actual node location. Note that this could apply to the first node of a lane. Lane width is the perpendicular distance between the center of the lane markers as defined in CVPFS Guidance Document for MAP Message Preparation.

Refer to the CVPFS Guidance Document for MAP Message Preparation for additional guidance.

6.3.3.4.1.23 Node Lane Width Change

A connected intersection shall define a node point anytime the lane width changes by more than 20 cm from the previous node point. Node spacing must also support accurate reporting of lane width changes.

6.3.3.4.2 Lane Attributes

The requirements to describe the allowed use of a lane at an intersection follow.

6.3.3.4.2.1 Direction of Travel

A connected intersection shall identify the allowable direction(s) of travel for a lane, as defined by DE_LaneDirection in SAE J2735.

6.3.3.4.2.2 Lane Sharing

A connected intersection shall identify the allowed user types that are permitted to use the lane, as defined by DE_LaneSharing in SAE J2735.

6.3.3.4.2.3 Lane Type Attributes

A connected intersection shall identify the attribute information specific to a given lane type, as defined by DE_LaneTypeAttributes in SAE J2735. The types of lanes are vehicle lane, crosswalk, bike lane, sidewalk, medians and channels, striped lanes, tracked lanes (for trains and trolleys), and parking lanes. If these lanes are present, then they must be mapped.

6.3.3.4.2.4 Lane Attributes - Vehicle

A connected intersection shall indicate the applicable attributes for a vehicle lane, as defined by DE_LaneAttributes-Vehicle in SAE J2735. Examples of attributes are if the lane is a revocable lane, and any lane restrictions (HOV, Taxi, private use, etc.).

6.3.3.4.2.5 Lane Attributes - Crosswalk

A connected intersection shall indicate the applicable attributes for a crosswalk, as defined by DE_LaneAttributes-Crosswalk in SAE J2735. Examples of attributes are if the lane is a revocable lane, and how the signal timing at the signalized intersection addresses travelers in the crosswalk lane.

6.3.3.4.2.6 Lane Attributes - Bicycle

A connected intersection shall indicate the applicable attributes for a bicycle lane, as defined by DE_LaneAttributes-Bike in SAE J2735. Examples of attributes are if the lane is a revocable lane, and how the signal timing at the signalized intersection addresses travelers in the bicycle lane.

DRAFT

6.3.3.4.2.7 Lane Attributes - Tracked Vehicles

A connected intersection shall indicate the applicable attributes for a tracked vehicle lane, as defined by DE_LaneAttributes-TrackedVehicle in SAE J2735. Examples of attributes are if the lane is a revocable lane, and the type of track (commuter rail, light rail, etc.).

6.3.3.4.2.8 Lane Attributes - Parking

A connected intersection shall indicate the applicable attributes for a parking lane, as defined by DE_LaneAttributes-Parking in SAE J2735. Examples of attributes are if the lane is a revocable lane, and the type of parking (parallel, head in parking, do not park zone, private parking, etc.).

6.3.3.4.3 Lane Maneuvers

A connected intersection shall identify for each ingress lane each maneuver that is allowed for that lane from the first node of the ingress lane (i.e., stop line) to the first node of the egress lane that the maneuver applies, as defined by DE_AllowedManeuvers in SAE J2735.

6.3.3.4.4 Connections between Lanes

The requirements to describe connections between a lane entering or within an intersection, and the downstream lane at an intersection follow.

6.3.3.4.4.1 Lane Connections

A connected intersection shall identify each permitted connection for an ingress lane between the ingress lane and each downstream lane at the intersection.

NOTE: The downstream lane may be another ingress lane, although it is not recommended. See 7.3.3.4.4.2.

6.3.3.4.4.2 Connection Egress Lane

For each permitted connection between an ingress lane and another lane, a connected intersection shall identify the other lane to which the ingress lane connects.

6.3.3.4.4.3 Connection Maneuvers

For each permitted connection between an ingress lane and the downstream lane, a connected intersection shall identify the maneuver the connection allows. Examples of a maneuver include left turn, straight ahead, right turn on red, always yield, go after a full stop, etc.

6.3.3.4.4.4 Connection Signal Group

For each permitted connection between an ingress lane and the downstream lane, a connected intersection shall identify the SPaT signal group that provides traffic signal control for that connection.

6.3.3.4.4.5 Include Only Permitted Connections

A connected intersection shall only identify a connection between a lane and a downstream lane at the intersection if the movement represented by that connection is allowed at the intersection. If a permitted connection does not exist at an intersection, that connection is not included in the MAP message.

DRAFT

6.3.3.4.5 Speed Limit Information Requirements

The requirements to provide the speed limit for a lane at the intersection follow.

6.3.3.4.5.1 Default Speed Limit

A connected intersection shall define the default speed limit for general traffic, in units of 0.02 m/s, for the intersection.

6.3.3.4.5.2 Change in Lane Speed Limit

If the speed limit for a lane is different from the default speed limit defined in the SAE J2735 MAP message, a connected intersection shall define the posted, regulatory, or statutory speed limit, in units of 0.02 m/s, for the lane starting at the node point where that speed limit is in effect.

A SAE J2735 MAP message contains a default speed limit for the intersection (see 6.3.3.4.5.1), but the speed limit may be different for each lane (or approach) around the intersection. This requirement defines the speed limit for those other lanes if the speed limit is different.

NOTE: It is expected that the MAP message includes a node point at the location which this speed limit change occurs.

6.3.3.4.6 Revocable Lanes

At intersections having lanes with usage that is different at different times, such as lanes that by time of day are reversible, have turn restrictions, or have parking restrictions, a connected intersection shall define in the MAP message separate lanes for each variation of usage and designate each as a revocable lane.

6.3.3.4.7 Signal Timing and Roadway Geometry Information Synchronization

Refer to CTI 4501/1, 6.3.3.4.7, Signal Timing and Roadway Geometry Information Synchronization.

6.3.3.5 Positioning Messages

Not Applicable.

6.3.3.6 Vehicle Messages

Not Applicable.

6.3.4 Security Requirements

CTI 4501/3 contains the security requirements for a connected intersection.

Some of those security requirements are relevant to the generation and broadcast of MAP messages, and this section (6.3.4) references those requirements in CTI 4501/3.

Refer to CTI 4501/3, 6.3.4, for a definition of terms used for security requirements.

6.3.4.1 Data Trustworthiness: Sources and Processing

Refer to CTI 4501/3, 6.3.4.1, Data Trustworthiness: Sources and Processing.

6.3.4.2 Data Communications Security

Refer to CTI 4501/3, 6.3.4.2, Data Communications Security.

6.3.4.3 Trustworthiness of TSC-Originating Information

Refer to CTI 4501/3, 6.3.4.3, Trustworthiness of TSC-Originating Information.

6.3.4.4 Approaching Vehicle Information Trustworthiness: RSU

Not Applicable.

6.3.4.5 Approaching Vehicle Information Trustworthiness and AGP: TSC

Not Applicable.

6.3.4.6 Time Source Trustworthiness

Refer to CTI 4501/3, 6.3.4.6, Time Source Trustworthiness.

6.3.4.7 SPaT Message Trustworthiness and Reliability

Not Applicable.

6.3.4.8 MAP Message Contents Trustworthiness

Refer to CTI 4501/3, 6.3.4.8, MAP Message Contents Trustworthiness.

6.3.4.9 RTCM Message Contents Trustworthiness

Not Applicable.

6.3.4.10 Consistency between MAP and SPaT Messages

Refer to CTI 4501/3, 6.3.4.10, Consistency between MAP and SPaT Messages.

6.3.4.11 Unavailability Indications

The requirements for unavailability indications for a connected intersection follow.

6.3.4.11.1 Correctness of SPaT Availability Indications

Not Applicable.

6.3.4.11.2 Correctness of SPaT Unavailability Indications

Not Applicable.

6.3.4.11.3 Correctness of MAP Availability Indications

Refer to CTI 4501/3, 6.3.4.11.3, Correctness of MAP Availability Indications.

6.3.4.11.4 Correctness of MAP Unavailability Indications

Refer to CTI 4501/3, 6.3.4.11.4, Correctness of MAP Unavailability Indications.

6.3.4.12 Intersection Identifier Trustworthiness

Refer to CTI 4501/3, 6.3.4.12, Intersection Identifier Trustworthiness.

DRAFT

6.3.4.13 System Management and Recovery

Not Applicable.

6.3.4.14 Support Systems and Functions

Not Applicable.

6.3.4.15 Updates and Update Planning

Not Applicable.

6.3.4.16 System Operational Modes, Accesses, and Status

Not Applicable.

6.3.4.17 V2X Message Transmission

Refer to CTI 4501/3, 6.3.4.17, V2X Message Transmission.

6.3.4.18 CI Security Verification Requirements

Refer to CTI 4501/3, 6.3.4.18, CI Security Verification Requirements.

6.3.5 Operations and Maintenance Requirements

Refer to CTI 4501, 6.3.5, Operations and Maintenance Requirements.

7. SYSTEM DESIGN

Section 7 defines the system design details based on the requirements identified in the Functional Requirements section (see Section 6). Section 7 includes the following:

a. A tutorial.

b. A Requirements Traceability Matrix (RTM): The RTM links the requirements presented in 6.3 with the design details that describe how to fulfill each requirement. Using this table, each requirement can then be traced in a conformant way.

c. Design Details: Contains the details, guidance, and examples on how to fulfill a requirement.

Section 7 is intended for the following readers:

a. System integrators

b. Device manufacturers/vendors

c. Central system developers

d. Conformance testers

e. Other interested parties

For these readers, Section 7 is useful to understand how particular functions and information may be implemented to conform to CTI 4501.

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7.1 Tutorial

The Requirements Traceability Matrix (RTM) in 7.2 identifies the design details that fulfills each of the requirements defined in 6.3. The design details that fulfill the requirements can be categorized as follows:

- Design details that do not require additional explanation. Some requirements do not require additional details on how to fulfill the requirement – those requirements are identified by "No Further Design Details" in the RTM.
- Design details that can be found in another reference.
- Design details that require additional guidance or explanation. These design details are found in 7.3.

7.2 Requirements Traceability Matrix

The Requirements Traceability Matrix (RTM) links the requirements in 6.3 with the corresponding design details on the same line. Using this table, each requirement in 6.3 can thus be traced in a conformant way. Each requirement either points to other sections of the standard where the formal design details on how to fulfill the requirement is described, provides no additional design details because the requirement is self-explanatory, or points to a normative reference that fulfills the requirement. In the latter case, the design details necessary to fulfill the requirement are contained within the normative reference.

To conform to a requirement, a connected intersection shall implement the design details traced from that requirement.

7.2.1 Notation [Informative]

7.2.1.1 Functional Requirement Columns

The functional requirements are defined within 6.3 and the RTM is based upon the requirements within that section. The section number and the functional requirement name are indicated within these columns.

7.2.1.2 Design Details

The "Design Details" column either provides a hyperlinked reference to a section number where the design details are defined within 7.3, provides an external, normative reference that provides the details on how to fulfill the requirement, or indicates "No Further Design Details" because no additional design information is necessary (i.e., the requirement is self-explanatory).

7.2.1.3 Additional Specifications

The "Additional Specifications" column may (and should) be used to provide additional notes and requirements or may be used by an implementer to provide any additional details about the implementation.

7.2.2 Instructions for Completing the RTM [Informative]

To find the conformant design content for a functional requirement, search for the requirement identification (section) number or functional requirement under the appropriate column. Next to the functional requirements column are columns that define the conformant design details that fulfill the requirement. The columns either reference a section within this document describing how the requirement is to be fulfilled; points to a normative reference describing how to fulfill the functional requirement; or indicates "No Further Design Details" because no additional design information is necessary. The "Additional Specifications" column provides additional notes or details about the design content.

Table 2 - Requirements traceability matrix

Requirements Traceability Matrix (RTM)			
FR ID	**Functional Requirement**	**Design Detail**	**Additional Specification**
6.3	Requirements		
6.3.1	Architectural Requirements		
		Refer to CTI 4501 Table 5, Requirements Traceability Matrix	
6.3.2	TSC Infrastructure to RSU Requirements	Not Applicable	
6.3.3	Message Requirements		
6.3.3.1	Message Performance Requirements		
6.3.3.1.1	Uniform Message Requirements		
6.3.3.1.1.1	SPaT Message - SAE J2735	Not Applicable	
6.3.3.1.1.2	SPaT Message - Mandatory Data Elements	Not Applicable	
6.3.3.1.1.3	SPaT Message - Required Data Elements	Not Applicable	
6.3.3.1.1.4	SPaT Message PSID	Not Applicable	
6.3.3.1.1.5	MAP Message - SAE J2735	Refer to MSG_MapData (MAP) in SAE J2735	
6.3.3.1.1.6	MAP Message - Mandatory Data Elements	Refer to MSG_MapData (MAP) in SAE J2735	
6.3.3.1.1.7	MAP Message - Required Data Elements	See 7.3.3.1.1.7, MAP Message - Required Data Elements Design Details	
6.3.3.1.1.8	MAP Message PSID	See 7.3.3.1.1.8, MAP Message PSID Design Details	
6.3.3.1.2	Robustness Requirements	Not Applicable	
6.3.3.1.3	Concise Messages Requirements		
6.3.3.1.3.1	Transport Message Size - WAVE	Refer to CTI 4501 Table 5, Requirements Traceability Matrix	
6.3.3.1.3.2	Concise MAP Message Requirements		
6.3.3.1.3.2.1	Nodes by Offsets	See 7.3.3.1.3.2.1, Nodes by Offsets Design Details	
6.3.3.1.3.2.2	Computed Lanes Requirements		
6.3.3.1.3.2.2.1	Computed Lane - Lane Identifier	See 7.3.3.1.3.2.2.1, Computed Lane - Lane Identifier Design Details	
6.3.3.1.3.2.2.2	Computed Lane - X-Offset	See 7.3.3.1.3.2.2.2, Computed Lane - X-Offset Design Details	
6.3.3.1.3.2.2.3	Computed Lane - Y-Offset	See 7.3.3.1.3.2.2.3, Computed Lane - Y-Offset Design Details	
6.3.3.1.3.2.2.4	Computed Lane - Angle	See 7.3.3.1.3.2.2.4, Computed Lane - Angle Design Details	
6.3.3.1.4	Advanced Notification Requirements	Refer to CTI 4501 Table 5, Requirements Traceability Matrix	
6.3.3.1.5	Timeliness Requirements		
6.3.3.1.5.1	SPaT Message - Broadcast Latency and Accuracy	Not Applicable	
6.3.3.1.5.2	SPaT Message - Broadcast Periodicity	No Further Design Details	

Requirements Traceability Matrix (RTM)			
FR ID	**Functional Requirement**	**Design Detail**	**Additional Specification**
6.3.3.1.5.3	MAP Message - Broadcast Periodicity	No Further Design Details	
6.3.3.1.6	Quality Assurance Requirements		
6.3.3.1.6.1	Completeness - SPaT Message	Not Applicable	
6.3.3.1.6.2	Completeness - MAP Message	See 7.3.3.1.6.2, Completeness - MAP Message Design Details	
6.3.3.1.6.3	SPaT Message - Time Mark Accuracy	Not Applicable	
6.3.3.2	Generic Message Requirements		
6.3.3.2.1	Time Accuracy	Not Applicable	
6.3.3.2.2	Message Revision Requirements		
6.3.3.2.2.1	SPaT Message - Revision Counter Increment	Not Applicable	
6.3.3.2.2.2	SPaT Message - Revision Counter Not Increment	Not Applicable	
6.3.3.2.2.3	MAP Message - Revision Counter Increment	See 7.3.3.2.2.3, MAP Message - Revision Counter Increment Design Details	
6.3.3.2.2.4	MAP Message - Revision Counter Not Increment	See 7.3.3.2.2.4, MAP Message - Revision Counter Not Increment Design Details	
6.3.3.2.2.5	MAP Message - Intersection Revision Counter Increment	See 7.3.3.2.2.5, MAP Message - Intersection Revision Counter Increment Design Details	
6.3.3.2.2.6	MAP Message - Intersection Revision Counter Not Increment	See 7.3.3.2.2.6, MAP Message - Intersection Revision Counter Not Increment Design Details	
6.3.3.2.2.7	RTCMcorrections Message - Sequence Number Increment	Not Applicable	
6.3.3.2.3	Timestamp Requirements	Not Applicable	
6.3.3.3	Signal Timing Data Requirements	Not Applicable	
6.3.3.4	Roadway Geometry Data Requirements		
6.3.3.4.1	Intersection Geometry Requirements		
6.3.3.4.1.1	Intersection Geometry Information	Refer to intersections (DF_IntersectionGeometryList) for MSG_MapData in SAE J2735	
6.3.3.4.1.2	Intersection Geometry - Road Authority Identifier	See 7.3.3.4.1.2, Intersection Geometry - Road Authority Identifier	
6.3.3.4.1.3	Intersection Geometry - Intersection Identifier	See 7.3.3.4.1.3, Intersection Geometry - Intersection Identifier Design Details	
6.3.3.4.1.4	Intersection Reference Point Requirements		
6.3.3.4.1.4.1	Intersection Reference Point - Position	See 7.3.3.4.1.4.1, Intersection Reference Point - Position Design Details	

Requirements Traceability Matrix (RTM)			
FR ID	**Functional Requirement**	**Design Detail**	**Additional Specification**
6.3.3.4.1.4.2	Intersection Reference Point - Description	See 7.3.3.4.1.4.2, Intersection Reference Point - Description Design Details	
6.3.3.4.1.5	Default Lane Width	See 7.3.3.4.1.5, Default Lane Width Design Details	
6.3.3.4.1.6	Lane Identifier	See 7.3.3.4.1.6, Lane Identifier Design Details	
6.3.3.4.1.7	Center of Vehicle Lane Geometry	See 7.3.3.4.1.7, Center of Vehicle Lane Geometry Design Details	
6.3.3.4.1.8	Center of Crosswalk Geometry	See 7.3.3.4.1.8, Center of Crosswalk Lane Geometry Design Details	
6.3.3.4.1.9	Center of Pedestrian Landings Geometry	See 7.3.3.4.1.9, Center of Pedestrian Landings Geometry Design Details	
6.3.3.4.1.10	Lane Description	See 7.3.3.4.1.10, Lane Description Design Details	
6.3.3.4.1.11	First Node Point - Ingress Vehicle Lane	See 7.3.3.4.1.11, First Node Point - Ingress Vehicle Lane Design Details	
6.3.3.4.1.12	First Node Point - Egress Vehicle Lane	See 7.3.3.4.1.12, First Node Point - Egress Vehicle Lane Design Details	
6.3.3.4.1.13	Node Offset from Intersection Reference Point	See 7.3.3.4.1.13, Node Offset from Intersection Reference Point Design Details	
6.3.3.4.1.14	Node Elevation Offset from Intersection Reference Point	See 7.3.3.4.1.14, Node Elevation Offset from Intersection Reference Point Design Details	
6.3.3.4.1.15	Offset from Previous Node	See 7.3.3.4.1.15, Offset from Previous Node Design Details	
6.3.3.4.1.16	Elevation Offset from Previous Node	See 7.3.3.4.1.16, Elevation Offset from Previous Node Design Details	
6.3.3.4.1.17	Advanced Notification - Ingress Vehicle Lane	See 7.3.3.4.1.17, Advanced Notification - Ingress Vehicle Lane Design Details	
6.3.3.4.1.18	End Nodes - Crosswalk Lane	See 7.3.3.4.1.18, End Nodes - Crosswalk Lane Design Details	
6.3.3.4.1.19	End Nodes - Pedestrian Landing	See 7.3.3.4.1.19, End Nodes - Pedestrian Landing Design Details	
6.3.3.4.1.20	Maximum Distance between Nodes	See 7.3.3.4.1.20, Maximum Distance between Nodes Design Details	
6.3.3.4.1.21	Maximum Number of Nodes	See 7.3.3.4.1.21, Maximum Number of Nodes Design Details	
6.3.3.4.1.22	Node Lane Width	See 7.3.3.4.1.22, Node Lane Width Design Details	
6.3.3.4.1.23	Node Lane Width Change	See 7.3.3.4.1.23, Node Lane Width Change	
6.3.3.4.2	Lane Attributes		
6.3.3.4.2.1	Direction of Travel	See 7.3.3.4.2.1, Direction of Travel Design Details	
6.3.3.4.2.2	Lane Sharing	See 7.3.3.4.2.2, Lane Sharing Design Details	
6.3.3.4.2.3	Lane Type Attributes	See 7.3.3.4.2.3, Lane Type Attributes Design Details	
6.3.3.4.2.4	Lane Attributes - Vehicle	See 7.3.3.4.2.4, Lane Attributes - Vehicle Design Details	
6.3.3.4.2.5	Lane Attributes - Crosswalk	See 7.3.3.4.2.5, Lane Attributes - Crosswalk Design Details	
6.3.3.4.2.6	Lane Attributes - Bicycle	See 7.3.3.4.2.6, Lane Attributes - Bicycle Design Details	
6.3.3.4.2.7	Lane Attributes - Tracked Vehicles	See 7.3.3.4.2.7, Lane Attributes - Tracked Vehicles Design Details	
6.3.3.4.2.8	Lane Attributes - Parking	See 7.3.3.4.2.8, Lane Attributes - Parking Design Details	
6.3.3.4.3	Lane Maneuvers	See 7.3.3.4.3, Lane Maneuvers Design Details	

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Requirements Traceability Matrix (RTM)			
FR ID	Functional Requirement	Design Detail	Additional Specification
6.3.3.4.4	Connections between Lanes		
6.3.3.4.4.1	Lane Connections	See 7.3.3.4.4.1, Lane Connections Design Details	
6.3.3.4.4.2	Connection Egress Lane	See 7.3.3.4.4.2, Connection Egress Lane Design Details	
6.3.3.4.4.3	Connection Maneuvers	See 7.3.3.4.4.3, Connection Maneuvers Design Details	
6.3.3.4.4.4	Connection Signal Group	See 7.3.3.4.4.4, Connection Signal Group Design Details	
6.3.3.4.4.5	Include Only Permitted Connections	See 7.3.3.4.4.5, Include Only Permitted Connections Design Details	
6.3.3.4.5	Speed Limit Information Requirements		
6.3.3.4.5.1	Default Speed Limit	See 7.3.3.4.5.1, Default Speed Limit Design Details	
6.3.3.4.5.2	Change in Lane Speed Limit	See 7.3.3.4.5.2, Change in Lane Speed Limit Design Details	
6.3.3.4.6	Revocable Lanes	See 7.3.3.4.6, Revocable Lanes Design Details	
6.3.3.4.7	Signal Timing and Roadway Geometry Information Synchronization		
6.3.3.4.7.1	Matching SPaT and MAP Version	Refer to CTI 4501/1 Requirements Traceability Matrix	
6.3.3.4.7.2	Matching Intersection Reference Identifiers	Refer to CTI 4501/1 Requirements Traceability Matrix	
6.3.3.4.7.3	Complete List of Signal Group Identifiers	Refer to CTI 4501/1 Requirements Traceability Matrix	
6.3.3.4.7.4	Matching Signal Group Identifier Movements	Refer to CTI 4501/1 Requirements Traceability Matrix	
6.3.3.5	Positioning Messages	Not Applicable	
6.3.3.6	Vehicle Messages	Not Applicable	
6.3.4	Security Requirements		
6.3.4.1	Data Trustworthiness: Sources and Processing	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.2	Data Communications Security	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.3	Trustworthiness of TSC-Originating Information	Not Applicable	
6.3.4.4	Approaching Vehicle Information Trustworthiness: RSU	Not Applicable	
6.3.4.5	Approaching Vehicle Information Trustworthiness and AGP: TSC	Not Applicable	
6.3.4.6	Time Source Trustworthiness	Not Applicable	
6.3.4.7	SPaT Message Trustworthiness and Reliability	Not Applicable	
6.3.4.8	MAP Message Contents Trustworthiness	Refer to CTI 4501/3 Requirements Traceability Matrix	

Requirements Traceability Matrix (RTM)			
FR ID	Functional Requirement	Design Detail	Additional Specification
6.3.4.9	RTCM Message Contents Trustworthiness	Not Applicable	
6.3.4.10	Consistency Between MAP and SPaT Messages	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.11	Unavailability Indications		
6.3.4.11.1	Correctness of SPaT Availability Indications	Not Applicable	
6.3.4.11.2	Correctness of SPaT Unavailability Indications	Not Applicable	
6.3.4.11.3	Correctness of MAP Availability Indications	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.11.4	Correctness of MAP Unavailability Indications	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.12	Intersection Identifier Trustworthiness	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.13	System Management and Recovery	Not Applicable	
6.3.4.14	Support Systems and Functions	Not Applicable	
6.3.4.15	Updates and Update Planning	Not Applicable	
6.3.4.16	System Operational Modes, Accesses, and Status	Not Applicable	
6.3.4.17	V2X Message Transmission	Not Applicable	
6.3.4.17.1	Prevent Change in Radio Coverage	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.17.2	Detect Change in Radio Coverage	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.17.3	Prevent Change in Radio Power	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.17.4	Detect Change in Radio Power	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.4.18	Refer to CTI 4501/3, 6.3.4.17, V2X Message Transmission. CI Security Verification Requirements	Refer to CTI 4501/3 Requirements Traceability Matrix	
6.3.5	Operations and Maintenance Requirements	Not Applicable	

7.3 Design Details

The design details to fulfill the requirements defined in 6.3 follow.

7.3.1 Architectural Design Details

Refer to CTI 4501 Table 5, Requirements Traceability Matrix, for the design guidance to fulfill the Architectural Requirements.

7.3.2 TSC Infrastructure to RSU Design Details

Not Applicable.

7.3.3 Message Design Details

The design details to fulfill the requirements for a connected intersection broadcasting messages to OBUs/MUs follow. These requirements are defined in 6.3.3.

7.3.3.1 Message Performance Design Details

The design details to fulfill the performance requirements for a connected intersection broadcasting messages to OBUs/MUs follow. These requirements are defined in 6.3.3.1.

7.3.3.1.1 Uniform Message Design Details

The design details to fulfill requirements to provide a consistent representation of the situation and operating conditions at a connected intersection follow. These requirements are defined in 6.3.3.1.1.

7.3.3.1.1.1 SPaT Message - SAE J2735 Design Details

Not Applicable.

7.3.3.1.1.2 SPaT Message - Mandatory Data Elements Design Details

Not Applicable.

7.3.3.1.1.3 SPaT Message - CI Mandatory Data Element Design Details

Not Applicable.

7.3.3.1.1.4 SPaT Message PSID Design Details

Not Applicable.

7.3.3.1.1.5 MAP Message - SAE J2735 Design Details

Refer to MSG_MapData (MAP) in SAE J2735.

7.3.3.1.1.6 MAP Message - Mandatory Data Elements Design Details

Refer to MSG_MapData (MAP) in SAE J2735.

7.3.3.1.1.7 MAP Message - Required Data Elements Design Details

Table 3 lists the data frames (begins with DF_) and the data elements (begins with DE_) in the MSG_MapData (MAP) message of SAE J2735 that are required to be supported to conform to CTI 4501. The data frames and data elements are nested and listed in the order they appear in the MAP message. All data frames and data elements listed in Table 3 shall be supported by a connected intersection; however, several data frames and data elements are not included in every broadcasted message under certain conditions.

The "SAE J2735 Mandatory" column indicates if the data frame or data element is mandatory to describe the roadway geometry for an intersection as defined in SAE J2735. A value of M indicates that the data frame or data element is mandatory, while a value of O indicates that the data frame or data element is optional. O.# (range) notation indicates that the data frame/element is part of an option group (#), and is used to show a set of selectable options. Support of the number of items indicated by the '(range)' is required from all options labeled with the same numeral #. A value of C indicates the data frame or data element is conditionally mandatory, meaning that the data frame or data element shall be broadcasted if certain conditions are met. The condition is also included in parentheses after the "C."

For example, O.2 (1..*) indicates that one or more of the option group 1 options shall be implemented. Each node point (nodes) must be described by a choice of node-XY1, node-XY2, node-XY3, node-XY4, node-XY5, or node-XY6. The (1..*) indicates that different node points may be described by more than one of the choices (i.e., it doesn't have to be the same choice to describe all the node points).

The "CTI 4501 Implementation" column indicates which data frames and data elements must be included in a broadcasted MAP message to conform with CTI 4501. A value of M indicates the data frame or data element must be included in every MAP message broadcasted. A value of C indicates the data frame or data element is conditionally mandatory, meaning that the data frame or data element shall be broadcasted if certain conditions are met. Two data elements in Table 3, region=RoadRegulatorID and fullRdAuthID=DE_FullRoadAuthorityID, are never sent in a MAP message.

Data frames and data elements for a MAP message that are not mandatory or conditionally mandatory to support RLVW applications are not included in Table 3 because no requirement has been defined for that data frame/data element in CTI 4501. Table B1 in Section B.1 provides a more view of the data structure for a MAP message.

For example, computed lanes (DF_ComputedLane) may not be needed or applicable to describe a lane associated with an intersection in a MAP message. In those situations, the data frames and data elements describing a computed lane should not be included in the MAP message, even though the connected intersection is capable of providing those data frames and data elements. However, if a computed lane is necessary, then it should be included in the MAP message. If the computed lane data frame (DF_ComputedLane) is included in the MAP message, then the data elements referenceLaneId, offsetXaxis, and offsetYaxis become mandatory and should also be included in the MAP message.

Note that the value in the "CTI 4501 Implementation" column is different from the "Conformance" column in the NRTM (refer to CTI 4501 Table 5) – the Conformance column defines if the implementation must support that requirement – it does not mean the data has to be sent in the MAP message.

For example, to conform to CTI 4501, the implementation is required to support changes in lane width in the MAP message, as indicated by the "M" in the Conformance column for requirement 6.3.3.4.1.22 in the NRTM. However, it is not required that the data element indicating a change in lane width (dWidth=DE_Offset_B10 under the "SAE J2735 Data Frames and Data Element" column) be included in the MAP message that is broadcasted, as indicated by the "C" in the CTI 4501 Implementation column.

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Table 3 - MAP message - Required elements

SAE J2735 Data Frames and Data Elements	SAE J2735 Mandatory	CTI 4501 Implementation
messageId=DE_DSRCmsgID=18 (MAP UPER)	M	M
msgIssueRevision=DE_MsgCount	M	M
intersections=DF_IntersectionGeometryList=1 to 32 X DF_IntersectionGeometry	O	M
id=DF_IntersectionReferenceID	M	M
region=RoadRegulatorID	O	Not used
id=DE_IntersectionID	M	M
revision=DE_MsgCount	M	M
refPoint=DF_Position3D	M	M
lat=DE_Latitude	M	M
long=DE_Longitude	M	M
elevation=DE_Elevation	O	M
laneWidth=DE_LaneWidth	O	M
speedLimits=DF_SpeedLimitList=1 to 9 x DF_RegulatorySpeedLimit	O	M
type=DE_SpeedLimitType	C (if speedLimits is included)	M
speed=DE_Velocity	C (if speedLimits is included)	M
laneSet=DF_LaneList=1 to 255 X DF_GenericLane	M	M
laneID=DE_LaneID	M	M
laneAttributes=DF_LaneAttributes	M	M
directionalUse=DE_LaneDirection	M	M
sharedWith=DE_LaneSharing	M	M
laneType=DF_LaneTypeAttributes=CHOICE	M	M
vehicle=DE_LaneAttributes-Vehicle	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.4)
crosswalk=DE_LaneAttributes-Crosswalk	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.5)
bikelane=DE_LaneAttributes-Bike	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.6)
trackedVehicle=DE_LaneAttributes-TrackedVehicle	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.7)
parking=DE_LaneAttributes-Parking	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.8)
maneuvers=DE_AllowedManeuvers	O	M
nodeList=DF_NodeListXY=CHOICE	M	M
nodes= DF_NodeSetXY=2 to 63 X DF_NodeXY	M	M
delta=DF_NodeOffsetPointXY	M	M
node-XY1=DF_Node_XY_20b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B10	C (if node-XY1 is included)	C (if node-XY1 is included - see 6.3.3.4.1.15)
y=DE_Offset_B10	C (if node-XY1 is included)	C (if node-XY1 is included - see 6.3.3.4.1.15)
node-XY2=DF_Node_XY_22b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B11	C (if node-XY2 is included)	C (if node-XY2 is included - see 6.3.3.4.1.15)
y=DE_Offset_B11	C (if node-XY2 is included)	C (if node-XY2 is included - see 6.3.3.4.1.15)
node-XY3=DF_Node_XY_24b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B12	C (if node-XY3 is included)	C (if node-XY3 is included - see 6.3.3.4.1.15)

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SAE J2735 Data Frames and Data Elements	SAE J2735 Mandatory	CTI 4501 Implementation
y=DE_Offset_B12	C (if node-XY3 is included)	C (if node-XY3 is included - see 6.3.3.4.1.15)
node-XY4=DF_Node_XY_26b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B13	C (if node-XY4 is included)	C (if node-XY4 is included - see 6.3.3.4.1.15)
y=DE_Offset_B13	C (if node-XY4 is included)	C (if node-XY4 is included - see 6.3.3.4.1.15)
node-XY5=DF_Node_XY_28b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B14	C (if node-XY5 is included)	C (if node-XY5 is included - see 6.3.3.4.1.15)
y=DE_Offset_B14	C (if node-XY5 is included)	C (if node-XY5 is included - see 6.3.3.4.1.15)
node-XY6=DF_Node_XY_32b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B16	C (if node-XY6 is included)	C (if node-XY6 is included - see 6.3.3.4.1.15)
y=DE_Offset_B16	C (if node-XY6 is included)	C (if node-XY6 is included - see 6.3.3.4.1.15)
attributes=DF_NodeAttributeSetXY	O	C (if data is included)
data=DF_LaneDataAttributeList=1 to 8 x DF_LaneDataAttribute	O	C (if data is included)
DF_LaneDataAttribute=CHOICE	O	C (if data is included)
speedLimits=DF_SpeedLimitList=1 to 9 X DF_RegulatorySpeedLimit	O	C (if data is included - see 6.3.3.4.5.2)
type=DE_SpeedLimitType	C (if speedLimits is included)	C (if data is included - see 6.3.3.4.5.2)
speed=DE_Velocity	C (if speedLimits is included)	C (if data is included - see 6.3.3.4.5.2)
dWidth=DE_Offset_B10	O	C (if dWidth is included - see 6.3.3.4.1.22)
dElevation=DE_Offset_B10	O	C (if dElevation is included - see 6.3.3.4.1.16)
computed=DF_ComputedLane	O	C (if computed is included - see 6.3.3.1.3.2.2)
referenceLaneId=DE_LaneID	C (if computed is selected)	C (if computed is included - see 6.3.3.1.3.2.2.1)
offsetXaxis=CHOICE	C (if computed is selected)	C (if computed is included - see 6.3.3.1.3.2.2.2)
small=DE_DrivenLineOffsetSmall	O.3 (1) (if computed is selected)	O.6 (1) (if computed is included - see 6.3.3.1.3.2.2.2)
large=DE_DrivenLineOffsetLarge	O.3 (1) (if computed is selected)	O.6 (1) (if computed is included - see 6.3.3.1.3.2.2.2)
offsetYaxis=CHOICE	C (if computed is selected)	C (if computed is included - see 6.3.3.1.3.2.2.3)
small=DE_DrivenLineOffsetSmall	O.4 (1) (if computed is selected)	O.7 (1) (if computed is included - see 6.3.3.1.3.2.2.3)
large=DE_DrivenLineOffsetLarge	O.4 (1) (if computed is selected)	O.7 (1) (if computed is included - see 6.3.3.1.3.2.2.3)
rotateXY=DE_Angle	O	O (if computed is included - see 6.3.3.1.3.2.2.4)
connectsTo=DF_ConnectsToList=1 to 16 X DF_Connection	O	M

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SAE J2735 Data Frames and Data Elements	SAE J2735 Mandatory	CTI 4501 Implementation
connectingLane=DF_ConnectingLane	C (if connectsTo is selected)	M
lane=DE_LaneID	C (if connectsTo is selected)	M
maneuvers=DE_AllowedManeuver	O	M
signalGroup=DE_SignalGroupID	O	M
roadAuthorityID=DF_RoadAuthorityID(1)=CHOICE	O	C (if a child organization exists - see 6.3.3.4.1.2)
fullRdAuthID=DE_FullRoadAuthorityID(1)	O	Not used
relRdAuthID=DE_RelativeRoadAuthorityID(1)	O	C (if a child organization exists - see 6.3.3.4.1.2)

(1) Added in CTI 4501 v02.

Table 4 contains links to the specific sections in CTI 4501/2 with the design details for generating that data element value.

Table 4 - MAP message design details

SAE J2735 Data Frames and Data Elements	CTI 4501 Implementation
messageId=DE_DSRCmsgID=18 (MAP UPER)	See 7.3.3.1.1.5
msgIssueRevision=DE_MsgCount	See 7.3.3.2.2.3 and 7.3.3.2.2.4
intersections=DF_IntersectionGeometryList=1 to 32 X DF_IntersectionGeometry	See 7.3.3.4.1.1
id=DF_IntersectionReferenceID	
id=DE_IntersectionID	See 7.3.3.4.1.3
revision=DE_MsgCount	See 7.3.3.2.2.5 and 7.3.3.2.2.6
refPoint=DF_Position3D	See 7.3.3.4.1.4
lat=DE_Latitude	See 7.3.3.4.1.4
long=DE_Longitude	See 7.3.3.4.1.4
elevation=DE_Elevation	See 7.3.3.4.1.4
laneWidth=DE_LaneWidth	See 7.3.3.4.1.5
speedLimits=DF_SpeedLimitList=1 to 9 x DF_RegulatorySpeedLimit	See 7.3.3.4.5.1
type=DE_SpeedLimitType	See 7.3.3.4.5.1
speed=DE_Velocity	See 7.3.3.4.5.1
laneSet=DF_LaneList=1 to 255 X DF_GenericLane	
laneID=DE_LaneID	See 7.3.3.4.1.6
laneAttributes=DF_LaneAttributes	
directionalUse=DE_LaneDirection	See 7.3.3.4.2.1
sharedWith=DE_LaneSharing	See 7.3.3.4.2.2
laneType=DF_LaneTypeAttributes (revocable)	See 7.3.3.4.2.3
maneuvers=DE_AllowedManeuvers	See 7.3.3.4.3
nodeList=DF_NodeListXY=Choice of DF_NodeSetXY OR DF_ComputedLane	
nodes= DF_NodeSetXY=2 to 63 X DF_NodeXY	See 7.3.3.4.1.21
delta=DF_NodeOffsetPointXY	
node-XY1=DF_Node_XY_20b	See 7.3.3.4.1.15
x=DE_Offset_B10	See 7.3.3.4.1.15
y=DE_Offset_B10	See 7.3.3.4.1.15
node-XY2=DF_Node_XY_22b	See 7.3.3.4.1.15
x=DE_Offset_B11	See 7.3.3.4.1.15
y=DE_Offset_B11	See 7.3.3.4.1.15
node-XY3=DF_Node_XY_24b	See 7.3.3.4.1.15
x=DE_Offset_B12	See 7.3.3.4.1.15
y=DE_Offset_B12	See 7.3.3.4.1.15
node-XY4=DF_Node_XY_26b	See 7.3.3.4.1.15
x=DE_Offset_B13	See 7.3.3.4.1.15

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SAE J2735 Data Frames and Data Elements	CTI 4501 Implementation
y=DE_Offset_B13	See 7.3.3.4.1.15
node-XY5=DF_Node_XY_28b	See 7.3.3.4.1.15
x=DE_Offset_B14	See 7.3.3.4.1.15
y=DE_Offset_B14	See 7.3.3.4.1.15
node-XY6=DF_Node_XY_32b	See 7.3.3.4.1.15
x=DE_Offset_B16	See 7.3.3.4.1.15
y=DE_Offset_B16	See 7.3.3.4.1.15
attributes=DF_NodeAttributeSetXY	
data=DF_LaneDataAttributeList=1 to 8 x DF_LaneDataAttribute	
DF_LaneDataAttribute=Choice	
speedLimits=DF_SpeedLimitList=1 to 9 X DF_RegulatorySpeedLimit	See 7.3.3.4.5.2
type=DE_SpeedLimitType	See 7.3.3.4.5.2
speed=DE_Velocity	See 7.3.3.4.5.2
dWidth=DE_Offset_B10	See 7.3.3.4.1.22
dElevation=DE_Offset_B10	See 7.3.3.4.1.16
computed=DF_ComputedLane	See 7.3.3.1.3.2.2
referenceLaneId=DE_LaneID	See 7.3.3.1.3.2.2.1
offsetXaxis=Choice	See 7.3.3.1.3.2.2.2
small=DE_DrivenLineOffsetSmall	See 7.3.3.1.3.2.2.2
large=DE_DrivenLineOffsetLarge	See 7.3.3.1.3.2.2.2
offsetYaxis=Choice	See 7.3.3.1.3.2.2.3
small=DE_DrivenLineOffsetSmall	See 7.3.3.1.3.2.2.3
large=DE_DrivenLineOffsetLarge	See 7.3.3.1.3.2.2.3
rotateXY=DE_Angle	See 7.3.3.1.3.2.2.4
connectsTo=DF_ConnectsToList=1 to 16 X DF_Connection	See 7.3.3.4.4.1
connectingLane=DF_ConnectingLane	See 7.3.3.4.4.1
lane=DE_LaneID	See 7.3.3.4.4.2
maneuvers=DE_AllowedManeuver	See 7.3.3.4.4.3
signalGroup=DE_SignalGroupID	See 7.3.3.4.4.4
roadAuthorityID=DF_RoadAuthorityID(1)	
relRdAuthID=DE_RelativeRoadAuthorityID(1)	See 7.3.3.4.1.2

(1) Added in CTI 4501 v02.

7.3.3.1.1.8 MAP Message PSID Design Details

The PSID for the MAP message is defined in 6.3.3.1.1.8. The PSID is used for the destination address in broadcast WSM and in the app Permissions Field in the MAP signing certificate.

Refer to https://standards.ieee.org/products-programs/regauth/psid/public/.

7.3.3.1.2 Robustness Design Details

Not Applicable.

7.3.3.1.3 Concise Messages Design Details

The design details to fulfill the requirements to provide complete data describing the situation within the maximum message size supported by the communications stack follow. The requirements are defined in 6.3.3.1.3.

7.3.3.1.3.1 Transport Message Size - WAVE Design Details

Refer to CTI 4501 Table 5, Requirements Traceability Matrix, for the design guidance to fulfill the Transport Message Size - WAVE requirements.

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7.3.3.1.3.2 Concise MAP Message Design Details

The design details to fulfill the requirements for concise MAP messages follow. The requirements are defined in 6.3.3.1.3.2.

7.3.3.1.3.2.1 Nodes by Offsets Design Details

Although SAE J2735 allows describing the location of a node point of a lane using absolute latitude or longitude values, using offsets results in a more compact MAP message size. Using only offsets from an intersection reference point or a previous node point also simplifies the processing an OBU/MU must perform to understand the MAP message.

7.3.3.1.3.2.2 Computed Lane Design Details

The design details to fulfill the requirements for a computed lane follow. The requirements are defined in 6.3.3.1.3.2.2.

7.3.3.1.3.2.2.1 Computed Lane - Lane Identifier Design Details

The lane identifier of the reference lane for a computed lane is represented as referenceLaneId (DE_LaneId) and can be found under the data frame DF_ComputedLane in the MSG_MapData message in SAE J2735. All node attributes defined for the reference lane are also inherited by the computed lane.

Generally, computed lanes are used at intersections where adjacent lanes of the same width are entering or exiting the intersection. The left-most lane in the direction of traffic is recommended as the reference lane. The right-most lane (in the direction of traffic) generally has to consider permitted parking.

Be aware of potential issues with defining an adjacent lane as a computed lane when the referenced lane includes a change in the lane width. It is not clear how the lanes would contract or expand in width with adjacent lanes. Also, no guidance is provided at this time when the referenced lane includes sharp curves.

7.3.3.1.3.2.2.2 Computed Lane - X-Offset Design Details

The X-offset describes the difference, in centimeters, along the east-west axis between the first node point of the referenced lane to the first node point of the computed lane. Positive X offsets are to the east.

The x-offset for a computed lane from a referenced lane is represented as offsetXaxis and can be found under the data frame DF_ComputedLane in the MSG_MapData message in SAE J2735. offsetXaxis is a choice between DE_DrivenLineOffsetSmall or DE_DrivenLineOffsetLarge; the difference between the data elements is the size of the data elements. DE_DrivenLineOffsetSmall requires 12 bits of data and supports offsets up to 2047 cm to the east or west. DE_DrivenLineOffsetLarge requires 16 bits of data and supports offsets up to 32767 cm.

If the x-offset between the computed lane and the reference lane is less than 2047 cm, DE_DrivenLineOffsetSmall should be used.

Figure 3 illustrates an example of computed lanes for intersection mapping. In Figure 3, lanes #5, #15, #17, and #21 are computed from a reference (source) lane #3. The first node point for the computed lane is represented as X and Y offsets in centimeters as a green square from the first node point of the reference lane #3. In this example, the lane width is assumed as 360 cm and the width of the intersection as 1500 cm.

The node attributes associated with the reference lane cannot be changed for the computed (target) lanes.

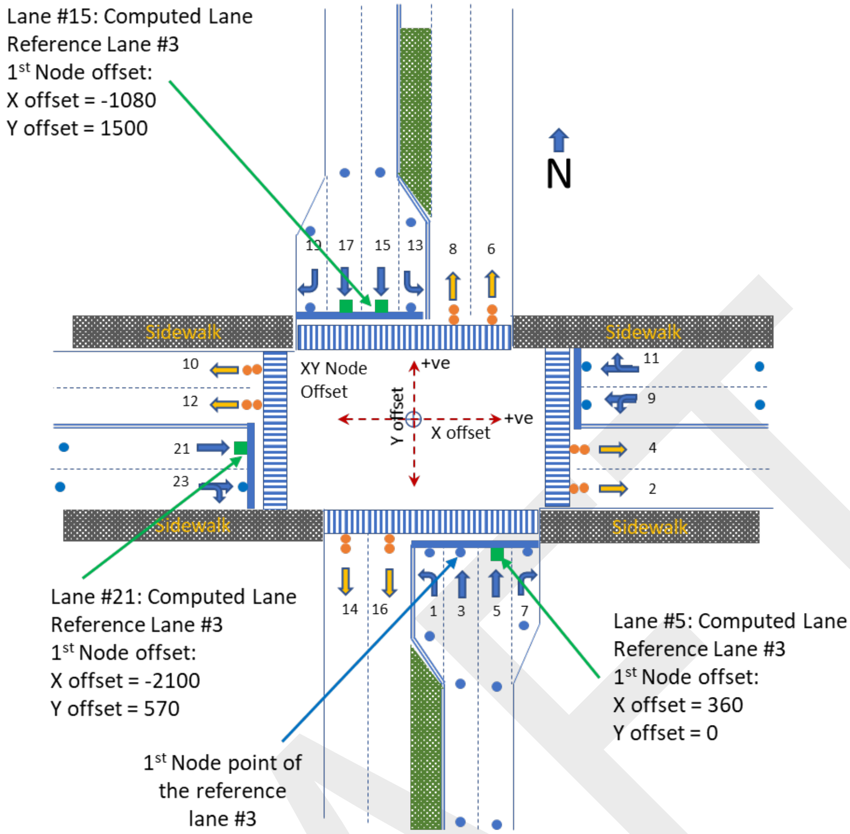

Figure 3 - Computed lane

The computed lane representation for lanes 5, 15, and 17 (The lane attributes are not shown) using Java Script Object Notation (JSON) encoding are the following:

```
{
 "laneID": 5,
 "laneAttributes": {…},
 "maneuvers": "8000",
 "nodeList": {
  "computed": [
   {
    "referenceLaneID": 3,
    "offsetXaxis": 360,
    "offsetYaxis": 0
   }
  ]
 }
},
{
 "laneID": 15,
 "laneAttributes": {…},
 "maneuvers": "8000",
 "nodeList": {
  "computed": [
   {
    "referenceLaneID": 3,
    "offsetXaxis": -1080,
    "offsetYaxis": 1500,
    "rotateXY": 14400
   }
  ]
 }
},
{
 "laneID": 21,
 "laneAttributes": {…},
```

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```
    "maneuvers": "8000",
    "nodeList": {
     "computed": [
       {
        "referenceLaneID": 3,
        "offsetXaxis": -2100,
        "offsetYaxis": 570,
        "rotateXY": 7200
       }
     ]
    }
  }
```


7.3.3.1.3.2.2.3 Computed Lane - Y-Offset Design Details

The y-offset describes the difference, in centimeters, along the north-south axis between the first node point of the referenced lane to the first node point of the computed lane. Positive Y offsets are to the north. The y-offset for a computed lane from a referenced lane is represented as offsetYaxis and can be found under the data frame DF_ComputedLane in the MSG_MapData message in SAE J2735. offsetYaxis is a choice between DE_DrivenLineOffsetSmall or DE_DrivenLineOffsetLarge; the difference between the data elements is the size of the data elements. DE_DrivenLineOffsetSmall requires 12 bits of data and supports offsets up to 2047 cm to the east or west. DE_DrivenLineOffsetLarge requires 16 bits of data and supports offsets up to 32767 cm.

If the y-offset between the computed lane and the reference lane is less than 2047cm, DE_DrivenLineOffsetSmall should be used.

See Figure 3 for an example illustration of a computed lane, followed by a sequence using JSON encoding.

7.3.3.1.3.2.2.4 Computed Lane - Angle Design Details

If the computed lane is oriented at a different angle from the referenced lane, the angle of the rotation value is represented as rotateXY (DE_Angle) and can be found under the data frame DF_ComputedLane in the MSG_MapData message in SAE J2735. The rotation value is expressed as unsigned units of 0.0125 degree (from 0 to 359.9875 degrees), with positive values to the east if the orientation of the lane is to the north (or to the right in the direction the traveler is facing).

The JSON encoding sequence for lane numbers 15 and 17 that follow Figure 3 are examples of how angle is presented in a computed lane.

7.3.3.1.4 Advanced Notification Design Details

Refer to CTI 4501 Table 5, Requirements Traceability Matrix, for the design guidance to fulfill the Advanced Notification Requirements.

7.3.3.1.5 Timeliness Design Details

The design details to fulfill the requirements for indicating changes in state, timing, and physical indications follow. The requirements are defined in 6.3.3.1.5.

7.3.3.1.5.1 SPaT Message - Broadcast Latency and Accuracy Design Details

Not Applicable.

7.3.3.1.5.2 MAP Message - Broadcast Periodicity Design Details

No design details provided at this time.

7.3.3.1.6 Quality Assurance Design Details

The design details to fulfill the requirements to provide quality information follow. These requirements are defined in 6.3.3.1.6.

7.3.3.1.6.1 Completeness - SPaT Message Design Details

Not Applicable.

7.3.3.1.6.2 Completeness - MAP Message Design Details

For a connected intersection, this requirement is fulfilled when the ingress lane and egress lane for every allowed movement through the intersection and controlled by the TSC infrastructure is represented in the MAP message. This includes all pedestrian crosswalks, bicycle lanes, and tracked vehicle lanes whose movements are controlled by the TSC infrastructure.

This requirement is verified by inspection.

7.3.3.1.6.3 SPaT Message - Time Mark Accuracy Design Details

Not Applicable.

7.3.3.2 Generic Message Design Details

The design details to fulfill requirements for a connected intersection transmitting data follow. These requirements are defined in 6.3.3.2.

7.3.3.2.1 Time Accuracy Design Details

Refer to CTI 4501 Table 5, Requirements Traceability Matrix, for the design guidance to fulfill the Time Accuracy requirements.

7.3.3.2.2 Message Revision Counter Design Details

The design details to fulfill the requirements to see if the data transmitted by a connected intersection is new follow. These requirements are defined in 6.3.3.2.2.

7.3.3.2.2.1 SPaT Message - Revision Counter Increment Design Details

Not Applicable.

7.3.3.2.2.2 SPaT Message - Revision Counter Not Increment Design Details

Not Applicable.

7.3.3.2.2.3 MAP Message - Revision Counter Increment Design Details

The revision counter for a MAP message is represented by msgIssueRevision (DE_MsgCount) and found in the MSG_MapData message in SAE J2735.

This requirement is verified by inspection.

7.3.3.2.2.4 MAP Message - Revision Counter Not Increment Design Details

This requirement is verified by inspection.

7.3.3.2.2.5 MAP Message - Intersection Revision Counter Increment Design Details

The revision counter for the geometric description of an intersection is represented by revision (DE_MsgCount) and found under the data frame DF_IntersectionGeometry in the MSG_MapData message in SAE J2735.

This requirement is verified by inspection.

7.3.3.2.2.6 MAP Message - Intersection Revision Counter Not Increment Design Details

This requirement is verified by inspection.

7.3.3.2.3 Timestamp Design Details

Not Applicable.

7.3.3.3 Signal Timing Data Design Details

Not Applicable.

7.3.3.4 Roadway Geometry Data Design Details

The design details to fulfill the requirements to provide information about travel lanes follow. These requirements are defined in 6.3.3.4.

7.3.3.4.1 Intersection Geometry Design Details

The design details to fulfill the requirements to provide information about the lanes in and around an intersection follow. These requirements are defined in 6.3.3.4.1.

7.3.3.4.1.1 Intersection Geometry Information Design Details

Refer to intersections (DF_IntersectionGeometryList) for MSG_MapData in SAE J2735.

7.3.3.4.1.2 Intersection Geometry - Road Authority Identifier Design Details

The road authority identifier is represented as a relative object identifier and found as a CHOICE under the data frame DF_RoadAuthorityID in the MSG_MapData message in SAE J2735. The CHOICE DE_FullRoadAuthorityID under the data frame DF_RoadAuthorityID is not used.

The road authority identifier represents a partition under the OpOrgID and may represent a regional district, or local jurisdiction (e.g., city, town, county). The road authority identifier is included in the MAP message to identify a child organization or another organization under the OpOrgID – if no organization exists, then the road authority identifier is not sent. Refer to CTI 4501 Section A.1 for a detailed description.

7.3.3.4.1.3 Intersection Geometry - Intersection Identifier Design Details

The intersection reference identifier is represented as id (DE_IntersectionID) and found under the data frame DF_IntersectionReferenceID in the MSG_MapData message in SAE J2735.

The intersection reference identifier is assigned by the road authority represented by the combination of the OpOrgID and Relative Road Authority ID, should the latter be included.

NOTE: Updated in CTI 4501 v02 from road regulator identifier to use OpOrgID in the IEEE 1609.2 certificate to identify the road authority.

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7.3.3.4.1.4 Intersection Reference Point Design Details

The design details to fulfill the requirements for the location of an intersection reference point follow. These requirements are defined in 6.3.3.4.1.4.

7.3.3.4.1.4.1 Intersection Reference Point - Position Design Details

Although the requirement states that the first node point should be within 327.67 m of the intersection reference point, the preference is that the selected intersection reference point should be located such that the first node point of all lanes associated with the intersection can be represented by DE_Offset_B13 (within 40.95 m) to allow the vehicle application to properly identify the intersection that is relevant as opposed to the other intersections that are in close proximity within the RF range.

It is recommended to define the reference point to be consistent with the CVPFS Guidance Document for MAP Preparation, which is:

- The reference point must be located inside the intersection defined by the MAP message
- Reference point location is established using a verified point marker, which is a surveyed physical object in or near the intersection, to ensure required accuracy

Refer to CVPFS Guidance Document for MAP Preparation document for further details on establishing the reference point.

7.3.3.4.1.4.2 Intersection Reference Point - Description Design Details

An intersection's reference point is represented as refpoint (DF_Position3D) and found under the data frame DF_IntersectionGeometry in MSG_MapData message in SAE J2735.

DF_Position3D consists of three data elements to represent the position. Latitude is represented as lat (DE_Latitude), longitude is represented as long (DE_Longitude), and elevation is represented as elevation (DE_Elevation) in DF_Position3D. The reference ellipsoid for DF_Position3D data elements is WGS-84.

The intersection reference point shall be corrected for local tectonic plate drift anytime the magnitude of drift exceeds 40 cm, which is two times the accuracy requirements, in the horizontal plane from the previous reported location. The geodetic epoch the reference point was established or last corrected must be known to track drift from this point in time.

Unlike SAE J2735, elevation is a mandatory element to conform with CTI 4501.

7.3.3.4.1.5 Default Lane Width Design Details

An intersection's default lane width is represented as laneWidth (DE_LaneWidth) and found under the data frame DF_IntersectionGeometry in MSG_MapData message in SAE J2735. All lanes associated with the intersection are assumed to be the default lane width unless otherwise indicated (see 7.3.3.4.1.22). Lane widths are represented in centimeter units.

7.3.3.4.1.6 Lane Identifier Design Details

Each lane associated with an intersection is assigned a unique lane identifier within that intersection. The lane identifier is represented as laneID (DE_LaneId) and found under the data frame DF_GenericLane for intersections in MSG_MapData message in SAE J2735.

The CI Committee considered several schemes for assigning lane identifiers for an intersection, but how each lane is assigned an identifier is inconsequential to an application on an OBU/MU, although there is a preference that the assignment scheme be consistent.

Schemes that have been used include assigning the first identifier for an approach to the leftmost lane, and assigning odd numbers to ingress lanes and even numbers to egress lanes, which work very well for roundabouts.

7.3.3.4.1.7 Center of Vehicle Lane Geometry Design Details

Each lane associated with an intersection is represented by node points that are located along the centerline of the lane. Each node point consists of an XY offset from a preceding node point, or the intersection's reference point. For the connected intersections, absolute positions (i.e., latitude, longitude points) are not permitted.

Read the guidance in 7.3.3.4.1.11 to 7.3.3.4.1.23 for additional details.

Also refer to the Connected Vehicle Pooled Fund Study's (CVPFS) Creation of a Guidance Document for MAP Preparation.

7.3.3.4.1.8 Center of Crosswalk Lane Geometry Design Details

Each crosswalk (lane) associated with an intersection is represented by node points that are located along the centerline of the crosswalk. Each node point consists of an XY offset from a preceding node point, or the intersection's reference point. For the connected intersections, absolute positions (i.e., latitude, longitude points) is not permitted.

Read the guidance in 7.3.3.4.1.13 to 7.3.3.4.1.16, 7.3.3.4.1.18, and 7.3.3.4.1.20 to 7.3.3.4.1.22 for additional details.

7.3.3.4.1.9 Center of Pedestrian Landings Geometry Design Details

Each pedestrian landing associated with an intersection is represented by node points that are located along the centerline of the landing. Each node point consists of an XY offset from a preceding node point, or the intersection's reference point. For the connected intersections, absolute positions (i.e., latitude, longitude points) are not permitted.

Read the guidance in 7.3.3.4.1.10, 7.3.3.4.1.13 to 7.3.3.4.1.16, and 7.3.3.4.1.19 to 7.3.3.4.1.22 for additional details.

7.3.3.4.1.10 Lane Description Design Details

See 7.3.3.4.1.11 to 7.3.3.4.1.16 for additional guidance.

7.3.3.4.1.11 First Node Point - Ingress Vehicle Lane Design Details

The first node point of an ingress vehicle lane is located at the upstream edge of the stop line.

Consistent with the CVPFS Guidance Document for MAP Message Preparation:

- In the absence of a stop line, the first node point should be placed on the upstream edge of a crosswalk marking.
- In the absence of a stop line and crosswalk marking, the first node point should be placed, using engineering judgement, at the nearest point at the upstream edge of the intersection.

The reason for the location of the first node point for an ingress lane is that the RLVW application needs to know where the stop line is because if the vehicle crosses the stop line (or the crosswalk marking) while the light is red, the vehicle is technically in violation, which the RLVW application tries to prevent. The RLVW application therefore needs to determine the distance from the stop line and not the distance to a location past the stop line. If the vehicle passes the stop line and stops in the crosswalk or at the edge of the intersection box while the light is red, the vehicle could get ticketed and the application design should not violate the law. Having the first node point at the location of the stop line also eliminates the need for an extra data element for the stop line location and reduces message size.

Beyond the mapped lane (i.e., downstream of the first node point), the application may have a hysteresis type design, where the lane the vehicle matched itself to is still maintained for a certain distance after crossing the first node point of the lane.

If the lane is bidirectional, such as a driveway, the first node point should follow the guidelines for the ingress direction, that is, located at the upstream edge of the stop line if present or the crosswalk marking.

Figure 4 provides several examples of locations for the first node point of lanes associated with an intersection. The first node point for most ingress lanes at this intersection are either at the upstream edge of the stop line if exists, or at the upstream edge of the crosswalk marking. Similarly, the first node point for all the egress lanes is at the downstream edge of the crosswalk, where crosswalk markings exist. However, since there is no stop line or crosswalk for lanes 2, 4, 9, or 11, engineering judgement is used to place the first node point of those lanes.

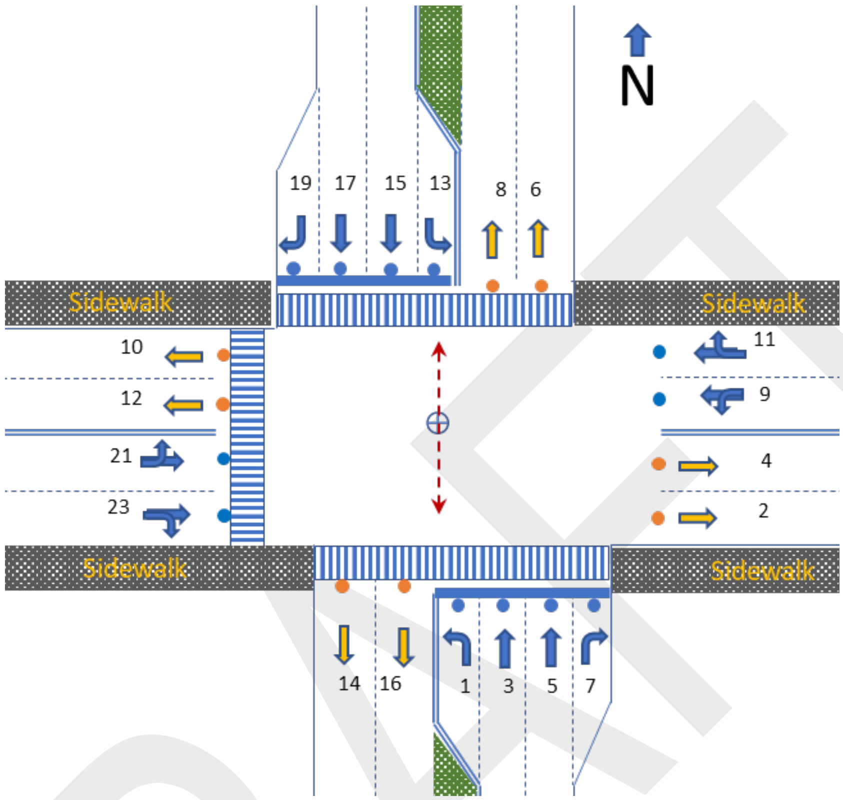

Figure 4 - First node point

NOTE: The ±20 cm node accuracy was derived from the following assumptions. For a vehicle to determine what lane it is in, for the worst case of a vehicle driving along the edge line the total error cannot be more than half the vehicle width or 80 cm for a small passenger vehicle. GNSS without RTCM Corrections allows the vehicle to determine its position within 60 cm. This difference leaves a requirement for 20 cm node accuracy. If augmentation (e.g., RTCM Corrections) is provided, then ±40/50 cm may be sufficient.

Because the intersection maps for connected intersections are generated using surveyed points that are aligned with the WGS 84 datum, drift of the underlying continental plate will move the intersection away from the GNSS locations of the originally surveyed node points. The North American Plate moves generally in a southwest direction at a speed of around 2.3 cm/yr. This would mean that a node that is surveyed with centimeter accuracy could move out of that accuracy requirement within between 10 years at the most and likely sooner.

Parts of the United States also are located on the Pacific Plate, which in California moves about 5 cm/yr to the northwest. This means that intersections west of the San Andreas Fault might have to be remapped more often than in other places in the country.

If the local plate movement vector is known, the MAP data could be corrected periodically and/or the intersections could be resurveyed every couple of years. By using offsets for the lane nodes, rather than absolute latitude and longitude, as required in this CI guidance, the entire intersection geometry can be corrected by simply correcting the reference point. All the other points then move to keep the same relative location from the reference point.

7.3.3.4.1.12 First Node Point - Egress Vehicle Lane Design Details

The first node point of an egress vehicle lane is located at the downstream edge of the crosswalk marking.

Consistent with Guidance Document for MAP Message Preparation:

- In the absence of crosswalk markings, the first node 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 (with or without crosswalk lines). For example, curbs or cross lanes of travel could be used as references to determine the boundary of the intersection.

The reason for the location of the first node point for an egress lane is that the RLVW application needs to know if the vehicle can clear an intersection, defined as the downstream edge of the crosswalk marking of the lane the vehicle is leaving the intersection before the light turns red. If the vehicle cannot clear the intersection, the vehicle is not satisfying the user need in CTI 4501, 5.4.2.3.2, Clear Intersection before Onset of Red Indication. The RLVW application therefore needs to determine the distance from the stop line of the ingress lane to the downstream edge of the crosswalk marking of the egress lane. If the vehicle does not clear the crosswalk marking while the light is red, the vehicle would not meet the design goal of clearing the intersection.

If a vehicle lane is reversible, the lane should be defined as two separate (revocable) lanes. So, when traveling in the ingress direction, the location of the first node point should follow the guidelines for an ingress lane, and when traveling in the egress direction, the first node point should follow the guidelines for an egress lane.

If the lane is bidirectional, such as a driveway, the first node point should follow the guidelines for the ingress direction, that is, located at the upstream edge of the stop line if present or the crosswalk marking. If there is no stop line or crosswalk marking, engineering judgement should be used.

See Figure 5 for several examples of locations for the first node point of egress lanes associated with an intersection.

NOTE: A RLVW application only needs one point to indicate the location of the egress lane. So, an egress lane can be described with two node points 1 cm apart. Based on this, the minimum length of the egress lane is 1 cm, represented by the first node point and a second node point 1 cm downstream. For the purposes of RLVW application, there is no need to extend the egress lane beyond 1 cm.

7.3.3.4.1.13 Node Offset from Intersection Reference Point Design Details

The first node point of all lanes at or associated with an intersection is described as a node offset from the intersection's reference point. Node offsets consist of an X value followed by a Y value and all are in 1 cm units. As indicated by SAE J2735, the offset is positive to the east (X) and to the north (Y).

The node offset is represented as a choice of different data frames (node-XY1, nodeXY-2, node-XY3, node-XY4, node-XY5, or node-XY6, represented by DF_Node_XY_20b, DF_Node_XY_22b, DF_Node_XY_24b, DF_Node_XY_26b, DF_Node_XY_28b, and DF_Node_XY_32b, respectively) and can be found under the data frame DF_NodeOffsetPointXY in the MSG_MapData message in SAE J2735.

The difference between the choices is the sizes of the offset data to be transmitted. Table 5 summarizes the differences between the choices, including the range of offsets supported for each choice and the number of bits required to transmit the choice. Note the number of bits required are for the X-offset and the Y-offset combined and each the same value.

Table 5 - Node offset ranges

Name	Data Frame	Range	Number of Bits Needed
node-XY1	DF_Node_XY_20b	±5.11 m	20
node-XY2	DF_Node_XY_22b	±10.23 m	22
node-XY3	DF_Node_XY_24b	±20.47 m	24
node-XY4	DF_Node_XY_26b	±40.96 m	26
node-XY5	DF_Node_XY_28b	±81.91 m	28
node-XY6	DF_Node_XY_32b	±327.67 m	32

The guidance is to use the smallest data frame if possible if there is a MAP message size issue, even if one lane uses different data frames (e.g., node-XY2 and node-XY4) to represent the node offsets for the same lane.

It is recommended that Universal Transverse Mercator (UTM) coordinates NOT be used because it introduces a rotation.

As shown in Figure 5, node offsets to the east are denoted by X offset and node offsets to the north by Y offset.

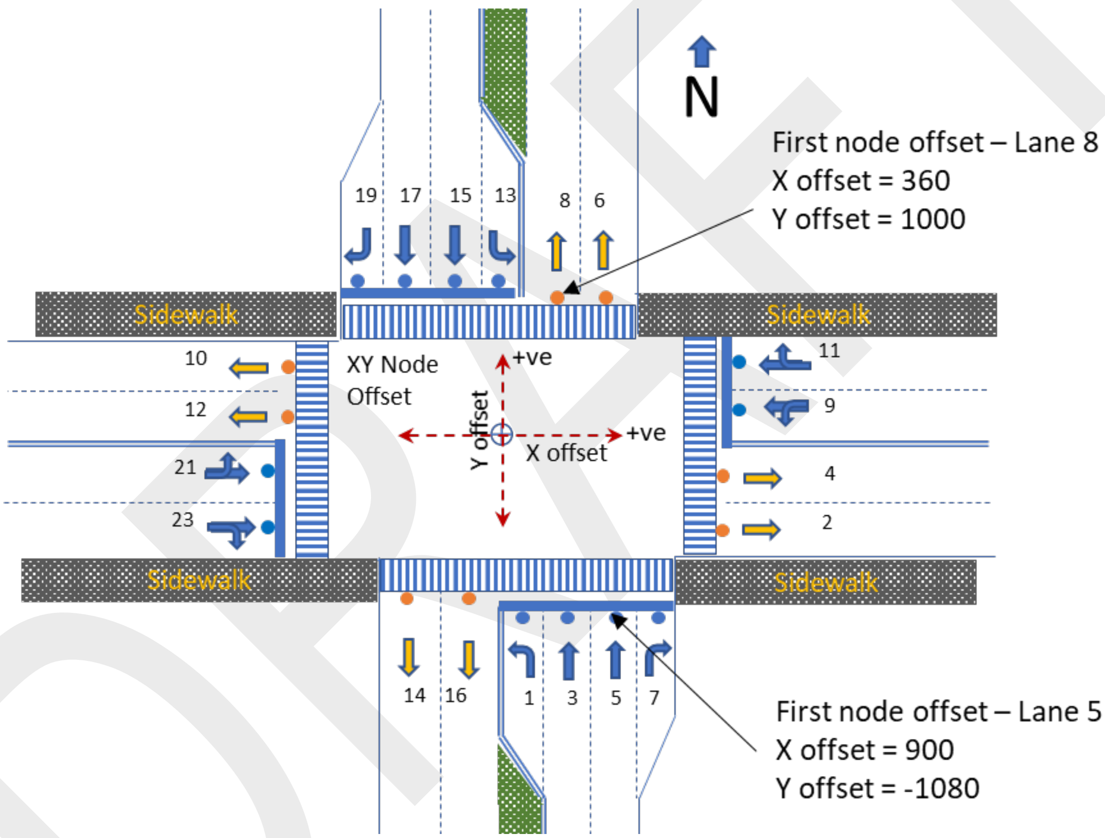

Figure 5 - First node point offsets

For Figure 5, the first node point for lane id 5 and lane id 8 are the following:


```
{
  "laneID": 5,
  "laneAttributes": {…},
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY3": {
            "x": 900,
            "y": -1080
          }
        }
      },
      {
        "delta": {}
      }
    ]
  }
},
{
  "laneID": 8,
  "laneAttributes": {…},
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY2": {
            "x": 360,
            "y": 1000
          }
        }
      },
      {
        "delta": {}
      }
    ]
  }
}
```


Note that since the first node point for lane id 8 is within 10.23 m of the intersection reference point for X- and Y-offsets (the range of node-XY2), node-XY2 is used to describe the location of the first offset node point lane 8. On the other hand, the first node point for lane id 5 is outside 10.23 m for the Y-offset, so node-XY3 is used to describe the location of the first offset node point lane 5.

7.3.3.4.1.14 Node Elevation Offset from Intersection Reference Point Design Details

The elevation of the first node point of all lanes at or associated with an intersection is described as an offset from the intersection's reference point, in 1 cm units. The elevation offset is represented as dElevation (DE_Offset-B10) and can be found under the data frame DF_NodeAttributeSetXY in the MSG_MapData message in SAE J2735.

If there is no change in elevation from the intersection reference point, this data element is not sent. A positive value indicates an increase in elevation from the intersection reference point.

Figure 6 is an example of a first node point that is at a different elevation than the intersection reference point.

DRAFT

7.3.3.4.1.15 Offset from Previous Node Design Details

Each subsequent node point after the first node point of all lanes at or associated with an intersection is described as a node offset from the previous node point. Node offsets consist of an X value followed by a Y value and all are in 1 cm units. As indicated by SAE J2735, the offset is positive to the east (X) and to the north (Y).

The node offset is represented as a choice of different data frames (node-XY1, nodeXY-2, node-XY3, node-XY4, node-XY5, or node-XY6, represented by DF_Node_XY_20b, DF_Node_XY_22b, DF_Node_XY_24b, DF_Node_XY_26b, DF_Node_XY_28b, and DF_Node_XY_32b, respectively) and can be found under the data frame DF_NodeOffsetPointXY in the MSG_MapData message in SAE J2735.

Table 5 in 7.3.3.4.1.13 describes the differences between the choices.

The guidance is to use the smallest data frame if possible, even if one lane uses different data frames (e.g., node-XY2 and node-XY4) to represent the offsets between node points for the same lane.

7.3.3.4.1.16 Elevation Offset from Previous Node Design Details

The elevation offset of a node point of a lane at or associated with an intersection from a previous node point is represented as dElevation (DE_Offset-B10) and can be found under the data frame DF_NodeAttributeSetXY in the MSG_MapData message in SAE J2735, in 1 cm units.

If there is no change in elevation from the previous node point, this data element is not sent. A positive value indicates an increase in elevation from the previous node point.

Changes in elevation are assumed to be a linear taper between the node points (it is a straight line between the two node points).

Note that SAE J2735 states that changes to elevation offsets persist to subsequent nodes.

See 7.3.3.4.1.20 for additional notes about vertical curves.

Figure 6 is a profile of a lane entering an intersection. The elevation of the first node point is located 20 cm higher than the elevation of the intersection reference point, and the second node point is also located 20 cm higher that the first node point. The third node point is at the same elevation as the second node point, while the fourth node point is 10 cm lower from the third node point.

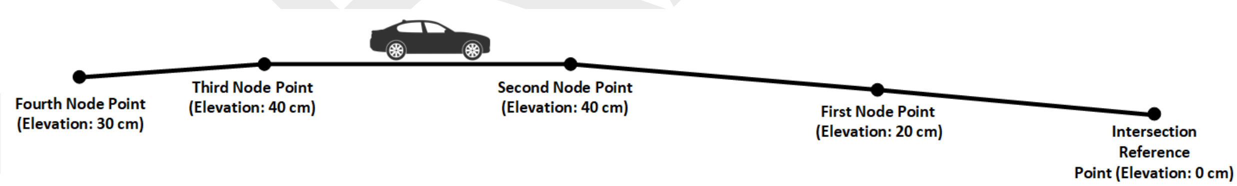

Figure 6 - Elevation offsets

The node point representation for this lane could be (JSON encoding) the following:


```
{
  "laneID": 3,
  "laneAttributes": {
    // ... lane attribute data here ...
  },
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY3": {
            "x": 540,
            "y": -1080
          }
        },
        "attributes": {
          "dElevation": 20
        }
      },
      {
        "delta": {
          "node-XY3": {
            "x": 0,
            "y": -1420
          }
        },
        "attributes": {
          "dElevation": 20
        }
      },
      {
        "delta": {
          "node-XY3": {
            "x": 0,
            "y": -1420
          }
        }
      },
      {
        "delta": {
          "node-XY1": {
            "x": 0,
            "y": -700
          }
        },
        "attributes": {
          "dElevation": -10
        }
      }
    ]
  }
```


DRAFT

7.3.3.4.1.17 Advanced Notification - Ingress Vehicle Lane Design Details

The requirement this design detail traces to provide guidance on how far upstream node points should be provided for an ingress lane into an intersection. In addition:

- This requirement requires that whenever possible, the 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. The recommendation is to use the 85th percentile speed in the calculation or the speed limit plus 7 mph if the 85th percentile speed is not available. For 25 mph, this is equivalent to an ingress lane 112 m long.

- Ingress lanes may or may not extend beyond the egress lanes of upstream intersections. This allows an OBU application to determine where a vehicle leaves the upstream intersection without having to process the ingress lane of the downstream intersection.

- However, ingress lanes may NOT extend into or beyond the conflict area of an upstream intersection. The rationale for this constraint is a concern that extending an ingress lane into an upstream intersection may cause confusion. This driver confusion is demonstrated in the scenarios below.

- It is recommended that if Intersection A in Figure 7 is within 10 seconds of vehicle travel in the ingress lane for Intersection B before the stop line AND Intersection A is NOT a connected intersection, i.e., is not broadcasting MAP and SPaT messages, that the MAP content describing the intersection geometry for Intersection A be included in the RSU broadcast for Intersection B. This could either be accomplished by a separate MAP message for Intersection A being broadcast by the RSU at Intersection B (i.e., Intersection B RSU would broadcast two MAP messages, one for each intersection) or could be accomplished by one MAP message that includes content describing two intersections (Intersections A and B). Including the adjoining non-CI intersection would allow the RLVW application to know not to provide warning/information before crossing the non-CI intersection.

- If Intersection A in Figure 7 is within 10 seconds of vehicle travel in the ingress lane for Intersection B before the stop line and Intersection A IS a connected intersection, the MAP content describing the intersection geometry of Intersection A may be included in the RSU broadcast for Intersection B. This could either be accomplished by a separate MAP message for Intersection A being broadcast by the RSU at Intersection B (i.e., Intersection B RSU would broadcast two MAP messages one for each intersection) or could be accomplished by one MAP message that includes content describing two intersections (Intersections A and B). This would allow an approaching vehicle to still receive information about Intersection A in case Intersection A stops broadcasting a MAP message for any reason.

To demonstrate the driver confusion if the ingress lanes extend into or beyond an upstream intersection, two scenarios are presented below.

The following pre-conditions are assumed:

- Intersections A and B are signalized intersections

- Speed limit is 45 mph

- Required MAP length (speed limit + 7mph) ≅ 230 m from stop point

- Distance between the Intersection A and B is 150 m

- RF transmission range of RSU ≅ 500 m

In Scenario 1, Intersections A and B in Figure 7 are signalized Connected Intersections (CI) broadcasting required messages to support in-vehicle RLVW application. Figure 7 shows operation and vehicle movements through the intersections.

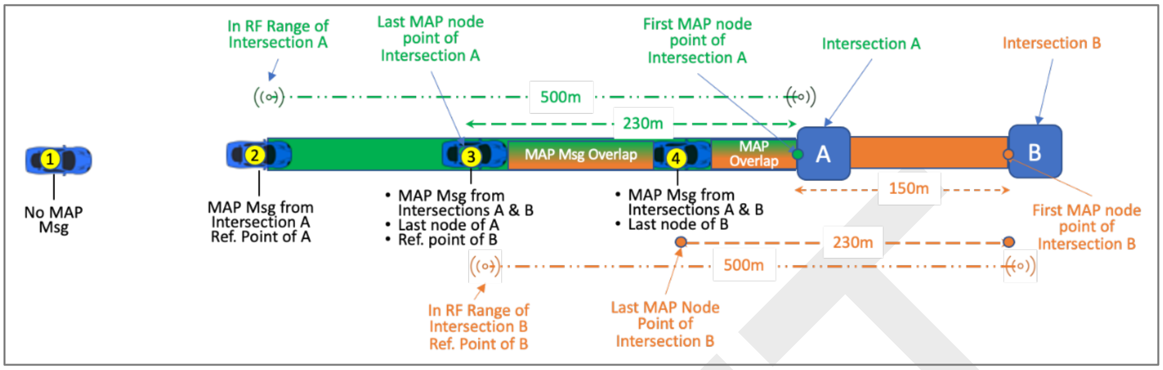

Figure 7 - Overlapping ingress lanes - Scenario 1

- When the approaching Connected Vehicle (CV) is at position 1, it is outside the broadcast range of RSU from intersection A, no messages are received.

- When the CV reaches position 2, it is within the broadcast range of 500 m from Intersection A and starts receiving messages from the intersection. At this location, the CV is 270 m away from the start of mapped lanes (map is up to 230 m from the intersection). The in-vehicle RLVW application can determine its lane position when the CV is in within mapped area. At this time, however, the reference point (from received MAP message) is known to establish relevance of approaching intersection by the application.

- When the CV reaches position 3, it is within mapped lane definition for Intersection A and within the broadcast range of Intersection B. The CV now has messages from both intersections.

- When the CV is at position 4, it is within defined map of Intersections A and B.

- In this scenario, the in-vehicle RLVW application would perform as intended for Intersection A (being the relevant intersection) followed by the Intersection B after crossing the intersection A. It is assumed that both connected intersections are operational, and broadcast required messages for the RLVW application at the time of CV traveling through the corridor.

- However, if Intersection A stops broadcasting MAP messages for any reason, such as an error condition, Scenario 2 below would occur.

DRAFT

In Scenario 2, Intersections A and B in Figure 8 are signalized intersections; however, Intersection A is not a Connected Intersection (CI) or not broadcasting required messages for RLVW application. Intersection B is broadcasting required messages to support in-vehicle RLVW application. Figure 8 shows operation and vehicle movements through the intersections.

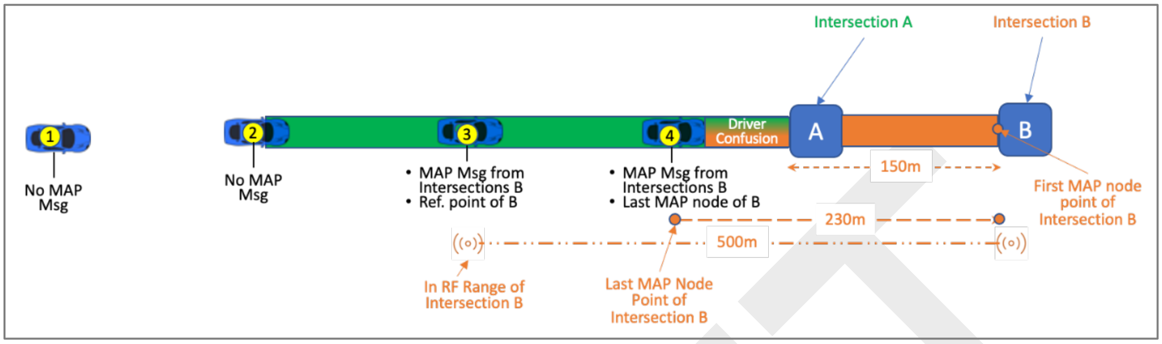

Figure 8 - Overlapping ingress lanes - Scenario 2

- When the approaching CV is upstream of position 3, the CV is outside the broadcast range of RSU from Intersection B and no messages are received by the CV.
- When the CV is at the position 3, it is within the broadcast range of 500 m from Intersection B. From the received MAP message, for next 270 m, the CV has the reference point location of the Intersection B, but the CV is not yet within the defined lane level map node points (maximum 230 m from the intersection) for the intersection to determine its lane position to associate with SPaT for RLVW application. The in-vehicle application, however, can establish the relevance of approaching intersection based on the reference point of the intersection from the MAP message.
- When the CV is downstream of position 4, it is within mapped lane definition for Intersection B for the in-vehicle application to determine its lane.
- When the CV is between the downstream from position 4 and before the stop point of Intersection A marked as "Driver Confusion" zone, the CV is approaching Intersection A. However, the intersection relevant to the in-vehicle application is Intersection B. When the CV is in the driver confusion zone and the signal phase is red or about to turn red for intersection A, the RLVW will not warn the driver since the application warning is for Intersection B and not A. This may confuse the CV operator since the operator is not aware that Intersection A is not a connected intersection, thinking that the RLVW system is not working.

7.3.3.4.1.18 End Nodes - Crosswalk Lane Design Details

The end nodes of a crosswalk shall be at the edge of a sidewalk curb, or a pedestrian landing. No guidance is provided on which end is the first node since the crosswalk is bidirectional.

7.3.3.4.1.19 End Nodes - Pedestrian Landing Design Details

The end nodes of a pedestrian landing shall be at the edge of the sidewalk curbs, or the crosswalk. No guidance is provided on which end is the first node since the pedestrian landing is bidirectional.

DRAFT

7.3.3.4.1.20 Maximum Distance between Nodes Design Details

For roadways with horizontal curves, the OBU application needs a certain amount of accuracy for lane-matching purposes. This requirement specifies that the maximum distance between the actual centerline of a lane and a straight line between node points not exceed 50 cm. To fulfill this requirement, the following formula provides the maximum distance between adjacent nodes based on the horizontal curve, where the spacing between node points *Ndist* is determined as a function of the maximum allowable centerline error *CLerr* and the radius of curvature *r*.

$$Ndist = 2\left(CLerr(2r - CLerr)\right)^{1/2}$$

Figure 9 provides the basis for how the above formula was derived.

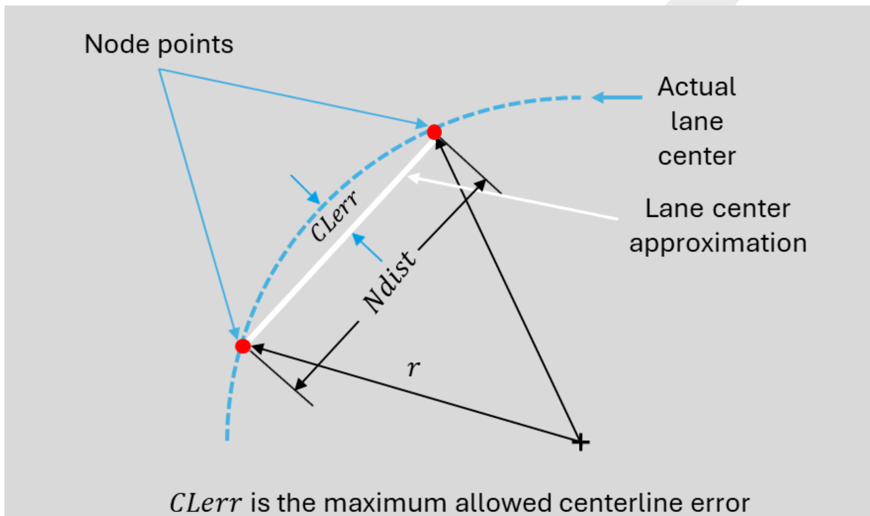

Figure 9 - Maximum distance between node points

Table 6 contains a suggested range of distance between node points for a curved segment.

Table 6 - Radius of curvature versus distance between nodes

Radius of Curvature (m)	Distance (Range) between Nodes (m)
51 to 100	14
101 to 200	20
201 to 300	28
301 to 400	34
401 to 500	40
501 to 600	44

DRAFT

For roadways with vertical curves, information is only needed for vehicle dynamics and for deceleration. A balance is needed when adding node points between the benefits of providing vertical curve information versus the cost of the increase in message size to provide that information. A general guideline is that additional node points are not needed when the changes in elevation are 20 cm or less between two consecutive node points (not cumulative). Recalling that changes in elevation are assumed to be a linear taper between the node points (it is a straight line between the two node points), be aware of sudden dips in elevation, such as illustrated in Figure 10.

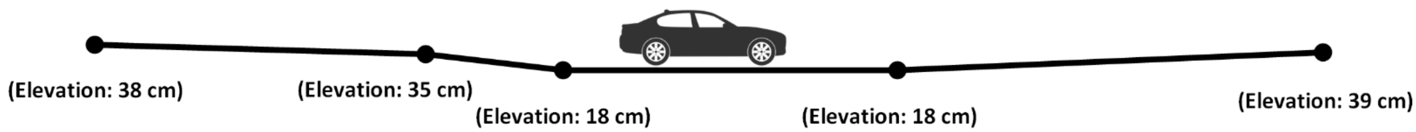

Figure 10 - Vertical curves

No additional guidance is provided at this time for the maximum distance between nodes based on vertical curves.

7.3.3.4.1.21 Maximum Number of Nodes Design Details

It is recommended to have as few node points as possible to describe a lane to minimize the size of the MAP message, while still fulfilling requirements described in 6.3.3.4.1.7 to 6.3.3.4.1.23.

7.3.3.4.1.22 Node Lane Width Design Details

The difference in the width of a lane at or associated with an intersection from the intersection's default lane width or from a previous node point is represented as dWidth (DE_Offset-B10) and can be found under the data frame DF_NodeAttributeSetXY in the MSG_MapData message in SAE J2735, in 1 cm units.

If there is no change in the lane width from the previous node point, this data element is not sent.

If there is no change in the lane width at the first node point for the lane from the default lane width for the intersection, this data element is not sent.

A positive value indicates an increase in the lane width from the previous node point.

Changes in lane widths are assumed to be a linear taper between the node points.

7.3.3.4.1.23 Node Lane Width Change Design Details

The lane/node accuracy requirement of ±20 cm is based on a study on allowable map error (accuracy) for a vehicle that is driving on the edge of a lane, assuming a standard 12-foot lane width for U.S. interstate highways. An accuracy requirement of less than ±20 cm should be considered if the lane width is less than 12 feet.

7.3.3.4.2 Lane Attributes Design Details

The design details to fulfill the requirements to describe the allowed use of a lane at an intersection follows. These requirements are defined in 6.3.3.4.2.

7.3.3.4.2.1 Direction of Travel Design Details

The allowable direction(s) of travel for a lane is represented as directionalUse (DE_LaneDirection) and can be found under the data frame DF_LaneAttributes in the MSG_MapData message in SAE J2735.

DE_LaneDirection is a bit string. A value of 1 for Bit 0 indicates that the lane is an ingress lane (travel is from the last node point for a lane to the first node point of the same lane). A value of 1 for Bit 1 indicates that the lane is an egress lane (travel is from the first node point for a lane to the last node point of the same lane). A value of 0 for both Bit 0 and Bit 1 indicates no travel is allowed. A value of 1 for both Bit 0 and Bit 1 indicates travel in both directions are allowed, for example, a pedestrian crosswalk.

For reversible vehicle lanes, separate lane identifiers should be assigned - one for each direction of travel, AND each lane should be identified as revocable lane (see 7.3.3.4.6).

7.3.3.4.2.2 Lane Sharing Design Details

A shared lane is a physical lane that can be shared by different types of travelers, each with a right to use the lane. A shared lane is represented by sharedWith (DE_LaneSharing) and can be found under the data frame DF_LaneAttributes in the MSG_MapData message in SAE J2735.

Common examples of shared lanes are tracked trolleys that share a vehicle lane, a bicycle lane that is shared with a vehicle lane, or a bicycle lane that is shared with a pedestrian pathway. For a connected intersection, how the lanes are coded in DE_LaneSharing depends on how the TSC infrastructure controls the different types of travelers.

For example, in Figure 11, the far-left lane is defined as lane 1, and may be used by motorized vehicles and the tracked vehicles. There is no separate signalGroupID to control different types of vehicles in this lane.

In this example, there is no need to map the same physical lane twice, because there are no separate signalGroupID assigned for motorized vehicles or tracked vehicles. So, the MAP message would assign Lane id 1 to this lane as a vehicle lane type (see 7.3.3.4.2.3). To indicate that the lane is treated as one for motorized vehicle and tracked vehicles, the multipleLanesTreatedAsOneLane bit is asserted to indicate that "the lane object path and width details represents multiple lanes within it that are not further described"; and trackedVehicleTraffic bit is asserted to indicate that "various modes and (the) type of traffic that may share this lane." The encoding for this example is as follows:

Bit #: 0123456789

Asserted bit: 0100000010

Figure 11 - Example shared lane

DRAFT

In Figure 12, the far-right lane is a shared lane with motorized vehicles and tracked vehicles. However, at the intersection, there are separate signal indications (signalGroupID) for the same shared lane, one for tracked vehicles and one for motorized vehicles.

For motorized vehicles, the lane is identified as Lane 5 and has a separate signalGroupID (3), while for tracked vehicles, the lane is identified as Lane 7, but has its own signalGroupID just for tracked vehicles. In this example, Lane 5 and 7, the overlapping bit should be asserted because the lane does overlap with another defined lane (lane 5 overlaps lane 7), and are defined as separate lanes. The encoding for this example is as follows:

Bit #: 0123456789

Asserted bit: 1000000010

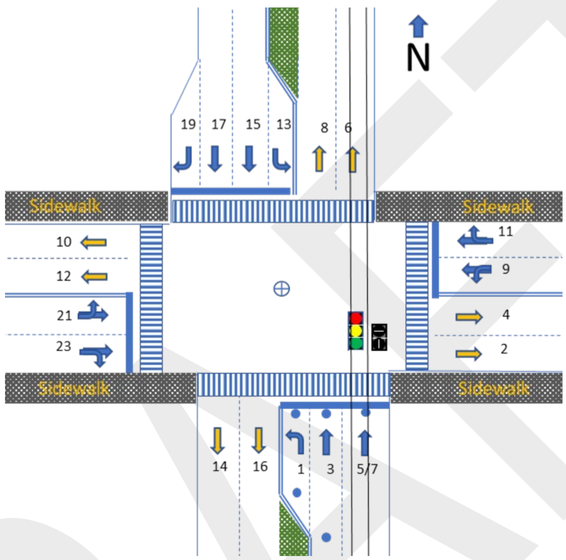

Figure 12 - Shared lane - Example 2

As a third example, to indicate that the lane is overlapping and is also shared by taxi vehicle traffic which may stop the vehicle to pick up and drop off customers, the overlappingLaneDescriptionProvided bit is asserted as:

Bit #: 0123456789

Asserted bit: 1000010000

DRAFT

7.3.3.4.2.3 Lane Type Attributes Design Details

The lane type, and its attributes, of a lane associated with an intersection is represented by laneType (DE_LaneTypeAttributes) and can be found under the data frame DF_LaneAttributes in the MSG_MapData message in SAE J2735.

The Lane Type Attributes data frame is used to hold attribute information specific to a given lane type choice and is defined as the following:

```
LaneTypeAttributes ::= CHOICE {
    vehicle
    crosswalk
    bikeLane
    sidewalk
    median
    striping
    trackedVehicle
    parking
... }
```

Each defined lane type contains bit flags depending on its application.

The attributes of a lane type are described in the following sections (7.3.3.4.2.4 to 7.3.3.4.2.8).

7.3.3.4.2.4 Lane Attributes - Vehicle Design Details

The attributes of a vehicle lane are described by vehicle (DE_LaneAttributes-Vehicle) and can be found under the data frame (DF_LaneTypeAttributes) in the MSG_MapData message in SAE J2735.

For example, to indicate a lane as a revocable vehicle lane but for HOV lane use only, the following bits are asserted:

Bit #: 01234567

Asserted bit: 10100000

7.3.3.4.2.5 Lane Attributes - Crosswalk Design Details

The attributes of a pedestrian crosswalk lane are described by crosswalk (DE_LaneAttributes-Crosswalk) and can be found under the data frame (DF_LaneTypeAttributes) in the MSG_MapData message in SAE J2735.

For example, to indicate a lane as a non-revocable crosswalk lane but the path allows bicycle traffic, the following bits are asserted:

```
Bit #:                111111
          0123456789012345
Asserted bit: 0010000000000000
```

7.3.3.4.2.6 Lane Attributes - Bicycle Design Details

The attributes of a bicycle lane are described by bikeLane (DE_LaneAttributes-Bike) and can be found under the data frame (DF_LaneTypeAttributes) in the MSG_MapData message in SAE J2735.

For example, to indicate lane as bicycle lane (not revocable) and the path allows pedestrian traffic, the following bit is asserted:

Bit #: 111111

0123456789012345

Asserted bit: 0100000000000000

7.3.3.4.2.7 Lane Attributes - Tracked Vehicles Design Details

The attributes of a tracked vehicle lane are described by trackedVehicle (DE_LaneAttributes-TrackedVehicle) and can be found under the data frame (DF_LaneTypeAttributes) in the MSG_MapData message in SAE J2735.

For example, to indicate the lane use restricted to certain vehicle types and restricted from public use, the following bit is asserted:

Bit #: 01234567

Asserted bit: 00000100

7.3.3.4.2.8 Lane Attributes - Parking Design Details

The attributes of a parking lane are described by parking (DE_LaneAttributes-Parking) and can be found under the data frame (DF_LaneTypeAttributes) in the MSG_MapData message in SAE J2735.

For example, to indicate the revocable parking lane for head-in parking in use, the following bits are asserted:

Bit #: 111111

0123456789012345

Asserted bit: 1010000000000000

7.3.3.4.3 Lane Maneuvers Design Details

The allowed lane maneuvers for a lane at an intersection is represented by maneuvers (DE_AllowedManeuvers) and can be found under the data frame (DF_GenericLane) in the MSG_MapData message in SAE J2735.

For example, to indicate a lane that allows straight, right turn on green and right turn on red, the following bits are asserted:

Bit #: 11

012345678901

Asserted bit: 101001000000

DRAFT

7.3.3.4.4 Connections between Lanes Design Details

The design details to fulfill the requirements to describe connections between a lane entering or within an intersection; and the downstream lane at an intersection follow. These requirements are defined in 6.3.3.4.4.

7.3.3.4.4.1 Lane Connections Design Details

A list of permitted connections between an ingress lane and each lane a traveler may connect to is represented by connectsTo (DF_ConnectsToList) and can be found under the data frame (DF_GenericLane) in the MSG_MapData message in SAE J2735.

The DF_ConnectsToList data frame is used to provide a sequence of other defined lanes to which an ingress lane connects beyond its stop point.

For example, to indicate connection between lanes, LaneID and allowed maneuvers are specified as follows (using JSON encoding):

```
"connectsTo": [
  {
    "connectingLane": {
      "lane": 10,
      "maneuver": "2400"
    },
    "signalGroup": 4
  }
]
```

where:

- "lane": "10" indicates LaneID to which the current lane connects to pass the stop point
- "maneuver": "2400" indicates the following bits are asserted to allow a right turn and a stop and then proceed when safe to turn right (Right Turn On Red Allowed)

  Bit #: 11

  012345678901

  Asserted bit: 001001000000

- "signalgroup": 4 indicates the SPaT signal group that controls the movements for that connection

7.3.3.4.4.2 Connection Egress Lane Design Details

The lane identifier of the egress lane from another lane at an intersection is represented by lane (DE_LaneID) and can be found under the data frame (DF_ConnectingLane) in the MSG_MapData message in SAE J2735.

An example of how an egress lane of a connection is represented lane is found in 7.3.3.4.4.1.

Although SAE J2735 allows the identifier of an egress lane to be the identifier of an ingress lane for a downstream intersection (see remoteIntersection (DF_IntersectionReferenceID) under the data frame (DF_Connection) in the MSG_MapData message), this is not recommended. By using the lane identifier of another intersection, the OBU application may need to process the MAP message for both intersections, and assumes that the OBU receives the MAP message describing the downstream intersection. The guidance is to use the identifier of the egress lane at the intersection, then link the egress lane to the ingress lane of the downstream intersection if connection to the downstream intersection is desired. The egress lane can be defined by two node points 1 cm apart. See 7.3.3.4.1.12 for additional guidance on egress lanes.

NOTE: Currently, lane connections can only be defined if the remoteIntersection has the same road authority identifier as the subject intersection.

DRAFT

7.3.3.4.4.3 Connection Maneuvers Design Details

The permitted connection describes the type of maneuvers that are allowed to complete a connection between an ingress lane and an egress lane (or the next connection). The type of maneuver is represented as maneuver (DE_AllowedManeuvers) and can be found under the data frame (DF_ConnectingLane) in the MSG_MapData message in SAE J2735.

An example snippet of a MAP message (using JSON encoding) for a permitted connection between an ingress lane and an egress lane is found in 7.3.3.4.4.1.

7.3.3.4.4.4 Connection Signal Group Design Details

If a permitted connection is controlled by a traffic signal indication (head), then the permitted connection is tied to an identifier called the signal group. Each signal group represents a collection of connections (or movements) that may be in an active state (e.g., permissive movement allowed or protected movement allowed) at the same time at the intersection.

The signal group is represented as signalGroup (DE_SignalGroupID) and can be found under the data frame (DF_Connection) in the MSG_MapData message in SAE J2735.

An example of a representation of a signal group is found in 7.3.3.4.4.1.

For every allowed connection defined for the intersection, there should be a corresponding signal group identifier for a movement state in the SPaT message, unless the connection is not controlled by the TSC infrastructure (refer to CTI 4501/1, 7.3.3.3.3.1, Current Movement State for a Signal Group), in which case the signalGroup data element is not sent.

7.3.3.4.4.5 Include Only Permitted Connections Design Details

Sending connections that are never permitted at an intersection can cause confusion and lead to errors.

For example, an agency may have a convention that identifies four pedestrian crossings at every signalized intersection. However, if a signalized intersection only has three pedestrian crossings, the connected intersection only includes the connections for those three pedestrian crossings.

If a connected intersection contains a connection that is permitted only under certain conditions, for example during a specific time of day or during special events, the ingress lane or downstream lane shall be defined as a revocable lane (see 6.3.3.4.6). The connection would only apply if the revocable lane is currently enabled in the SPaT message. The SPaT message also indicates if the connection is in effect or not (by indicating the current movement state for the signal group associated with that connection).

7.3.3.4.5 Speed Limit Information Design Details

The design details to fulfill the requirements to provide the speed limit for a lane at the intersection follows. These requirements are defined in 6.3.3.4.5.

7.3.3.4.5.1 Default Speed Limit Design Details

An intersection's default speed limits are represented as speedlimits (DF_SpeedLimitList) and found under the data frame DF_IntersectionGeometry in MSG_MapData message in SAE J2735. All lanes associated with the intersection are assumed to use these default speed limits unless otherwise indicated. The default speed limit is the posted speed limit, assuming this exists, otherwise it is the regulatory or statutory maximum speed limit, depending on which speed limit takes precedence for that jurisdiction.

Up to nine types of default speed limits can be defined for the intersection, along with a speed measured in 0.02 m/s. The type of speed limit is represented by DE_SpeedLimitType and speed is represented as DE_Velocity. Minimally, vehicleMaxSpeed is provided for DE_SpeedLimitType.

For example, the following MAP message segment in JSON indicates a maximum speed limit of 25 mph in a school zone when children are present. The speed limit is specified using the speedLimits data frame containing type (DE_SpeedLimitType) and speed (DE_Velocity) in 0.02 m/s units.


```
{
 "intersections": [
  {
   "id": {
    "id": 23
   },
   "revision": 1,
   "refPoint": {
    "lat": 425207879,
    "long": -830473419,
    "elevation": 1890
   },
   "laneWidth": 366,
   "speedLimits": {
    "type": "maxSpeedInSchoolZoneWhenChildrenArePresent",
    "speed": 559
   }
  }
 ]
}
```


7.3.3.4.5.2 Change in Lane Speed Limit Design Details

If a lane has a speed limit that differs from the default speed limit for the intersection, the lane attribute data shall include a lane speed limit. A lane's speed limits are represented as speedlimits (DF_SpeedLimitList) and found under the data frame DF_LaneDataAttribute in MSG_MapData message in SAE J2735.

If the speed limit for the lane is the same as the default speed limit for the intersection, speedlimits (DF_SpeedLimitList) is not sent.

Up to nine types of default speed limits can be defined for the lane, along with a speed measured in 0.02 m/s. The type of speed limit is represented by DE_SpeedLimitType, and speed is represented as DE_Velocity.

Any changes in the speed limit are asserted (apply) from the node point where the speed limit is first defined for the lane as ordered in the MAP message until a different speed limit is defined. For subsequent node points in the MAP message, if there is no change in the speed limit from the previous node point, speedlimits (DF_SpeedLimitList) is not sent.

For example, in Figure 13, the default speed limit for the intersection is 40 mph. However, for lanes 9 and 11, the maximum speed limit is 35 mph for the first 50 m from the stop line, then 45 mph upstream from that point. The maximum speed limit for lanes 10 and 12 is also 35 mph until 35 m.

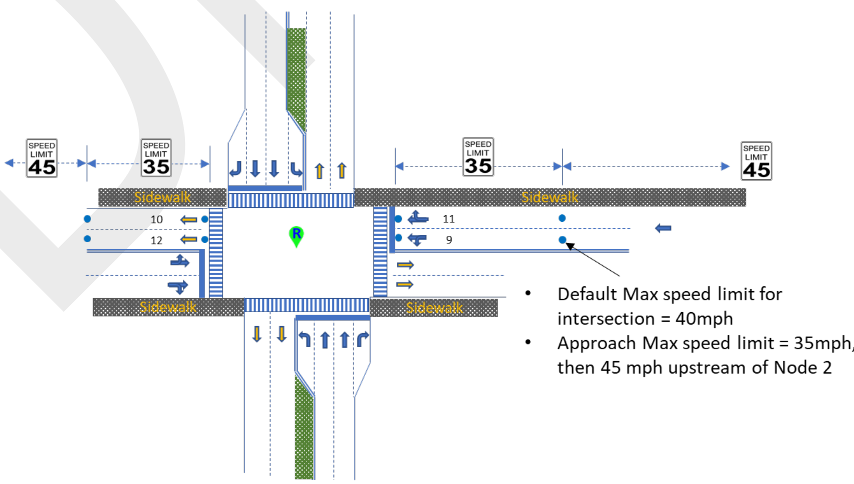

Figure 13 - Changes in lane speed limits

Using JSON encoding, the node points for lane ids 9, 10, 11, and 12 are the following:


```
{
  "laneID": 9,
  "laneAttributes": {
    // ...
  },
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY3": {
            "x": 1800,
            "y": 180
          }
        }
      },
      {
        "attributes": {
          "data": [
            {
              "speedLimits": [
                {
                  "speed": 782,
                  "type": "vehicleMaxSpeed"
                }
              ]
            }
          ]
        }
      },
      {
        "delta": {
          "node-XY5": {
            "x": 5000,
            "y": 0
          }
        }
      },
      {
        "attributes": {
          "data": [
            {
              "speedLimits": [
                {
                  "speed": 1008,
                  "type": "vehicleMaxSpeed"
                }
              ]
            }
          ]
        }
      }
    ]
  }
},
{
  "laneID": 10,
  "laneAttributes": {
    // ...
  },
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY3": {
            "x": -1700,
            "y": 180
          }
        }
      },
      {
        "attributes": {
          "data": [
```

```
          {
            "speedLimits": [
              {
                "speed": 782,
                "type": "vehicleMaxSpeed"
              }
            ]
          }
        ]
      }
    },
    {
      "delta": {
        "node-XY4": {
          "x": -3500,
          "y": 0
        }
      }
    },
    {
      "attributes": {
        "data": [
          {
            "speedLimits": [
              {
                "speed": 1008,
                "type": "vehicleMaxSpeed"
              }
            ]
          }
        ]
      }
    }
  ]
}
},
{
  "laneID": 11,
  "laneAttributes": {
    // ...
  },
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY3": {
            "x": 1800,
            "y": 540
          }
        }
      },
      {
        "attributes": {
          "data": [
            {
              "speedLimits": [
                {
                  "speed": 782,
                  "type": "vehicleMaxSpeed"
                }
              ]
            }
          ]
        }
      },
      {
        "delta": {
          "node-XY5": {
            "x": 5000,
            "y": 0
          }
        }
      },
      {
        "attributes": {
```

```
          "data": [
            {
              "speedLimits": [
                {
                  "speed": 1008,
                  "type": "vehicleMaxSpeed"
                }
              ]
            }
          ]
        }
      }
    ]
  }
},
{
  "laneID": 12,
  "laneAttributes": {
    // ...
  },
  "nodeList": {
    "nodes": [
      {
        "delta": {
          "node-XY3": {
            "x": -1700,
            "y": 180
          }
        }
      },
      {
        "attributes": {
          "data": [
            {
              "speedLimits": [
                {
                  "speed": 782,
                  "type": "vehicleMaxSpeed"
                }
              ]
            }
          ]
        }
      },
      {
        "delta": {
          "node-XY4": {
            "x": -3500,
            "y": 0
          }
        }
      },
      {
        "attributes": {
          "data": [
            {
              "speedLimits": [
                {
                  "speed": 1008,
                  "type": "vehicleMaxSpeed"
                }
              ]
            }
          ]
        }
      }
    ]
  }
}
```

7.3.3.4.6 Revocable Lanes Design Details

A revocable lane is a lane that is "active" only during certain periods of time. How a revocable lane is represented is dependent on the lane type and its attributes, as represented by laneType (DE_LaneTypeAttributes) in the data frame DF_LaneAttributes (see 7.3.3.4.2.3). For example:

- Lane attributes for a vehicle lane are represented by vehicle (DE_LaneAttributes-Vehicle) in the data frame DF_LaneTypeAttributes
- Lane attributes for a crosswalk lane are represented by crosswalk (DE_LaneAttributes-Crosswalk) in the data frame DF_LaneTypeAttributes
- Lane attributes for a bicycle lane are represented by bikeLane (DE_LaneAttributes-Bike) in the data frame DF_LaneTypeAttributes
- Lane attributes for a tracked vehicle lane are represented by trackedVehicle (DE_LaneAttributes-TrackedVehicle) in the data frame DF_LaneTypeAttributes
- Lane attributes for a parking lane are represented by parking (DE_LaneAttributes-Parking) in the data frame DF_LaneTypeAttributes

Regardless of the lane type, a revocable lane is represented by a value of 1 for Bit 0 of the DE_LaneAttributes-xxxx, where xxxx is the type of lane.

Whether the lane for an intersection is "active" or "enabled" is defined by the Enabled Lanes indication in the SPaT message for the same intersection (refer to CTI 4501/1, 7.3.3.3.7, Enabled Lanes Indication).

7.3.3.4.7 Signal Timing and Roadway Geometry Synchronization Design Details

Refer to CTI 4501 Table 5, Requirements Traceability Matrix, for the design guidance to fulfill the Signal Timing and Roadway Geometry Synchronization requirements.

7.3.3.5 Positioning Messages

Not Applicable.

7.3.3.6 Vehicle Messages Design Details

Not Applicable.

7.3.4 Security Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the Security Requirements in 6.3.4. Annex A contains the IEEE 1609.2 security profile for a security certificate that should be attached to a SAE J2735 MAP message.

7.3.4.1 Connected Intersection Data Trustworthiness Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the Data Trustworthiness: Sources and Processing requirements.

7.3.4.2 Connected Intersection Data Communications Security Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the Data Communications Security requirements.

7.3.4.3 Trustworthiness of TSC-Originating Information: Design Details

Not Applicable.

7.3.4.4 Approaching Vehicle Information Trustworthiness: RSU: Design Details

Not Applicable.

7.3.4.5 Approaching Vehicle Information Trustworthiness: TSC: Design Details

Not Applicable.

7.3.4.6 Time Source Trustworthiness: Design Details

Not Applicable.

7.3.4.7 SPaT Message Trustworthiness and Reliability: Design Details

Not Applicable.

7.3.4.8 MAP Message Contents Trustworthiness: Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the MAP Message Contents Trustworthiness requirements.

7.3.4.9 RTCM Message Trustworthiness and Reliability: Design Details

Not Applicable.

7.3.4.10 Consistency between MAP and SPaT Messages: Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the Consistency Between MAP and SPaT Messages requirements.

7.3.4.11 Unavailability Indications: Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the Unavailability Indications requirements.

7.3.4.12 Intersection Identifier Trustworthiness: Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the Intersection Identifier Trustworthiness requirements.

7.3.4.13 System Management and Recovery: Design Details

Not Applicable.

7.3.4.14 Support Systems and Functions: Design Details

Not Applicable.

7.3.4.15 Updates and Update Planning: Design Details

Not Applicable.

7.3.4.16 System Operational Modes, Accesses, and Status: Design Details

Not Applicable.

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7.3.4.17 V2X Message Transmission: Design Details

Not Applicable.

7.3.4.18 Verification of Connected Intersection System Security Design Details

Refer to CTI 4501/3 Table 1, Requirements Traceability Matrix, for the design guidance to fulfill the CI Security Verification Requirements.

7.3.5 Operations and Maintenance Design Details

Not Applicable.

8. CONNECTED INTERSECTION TESTING

This section presents a testing framework to verify that the MAP messages broadcasted by an implementation conform to CTI 4501. This testing framework provides guidance on how to create a verification plan that test MAP messages for a conformant CTI 4501 implementation. The purpose of a verification plan is to confirm that the implementation fulfills all the requirements defined for a connected intersection(s).

This section presents EXAMPLES of:

- Conformance Testing for MAP Message Verification

The reader is encouraged to read CTI 4501/4 before reading the remainder of this section.

8.1 Conformance Testing Areas

CTI 4501 conformance testing for MAP Message Verification can be characterized as:

- Describes the scope, testing activities and test documentation to verify a connected intersection fulfills the CTI 4501 requirements for a MAP message.

Two examples of different testing and verification methodologies to verify MAP message conformance to CTI 4501 are:

- Sections 8.2 and 8.3 in this document primarily presents the methodologies and example documentation that were used for testing and validation for Phase 1 of the Connected Intersections project, which resulted in the publication of CTI 4501 v01 and CTI 4502.

- SAE J3238/2 describes a standards-based testing and verifying methodology to verify the accuracy of MAP message node points using LiDAR based mobile mapping data. The contents of SAE J3238/2 are from FHWA-sponsored research performed by Crash Avoidance Metrics Partners, LLC (CAMP) under the Utah SMART Grant project Enabling Trust and Deployment through Verified Connected Intersections.

8.2 Requirements to Test Case Traceability Matrix (RTCTM)

An example requirements to test case traceability matrix (RTCTM) to verify MAP message conformance to CTI 4501 is provided in Table 7. The RTCTM is used to:

- Define the relationships between CTI 4501 requirements and specific (verification) test cases;

- Indicate what requirements might need to be tested to verify that an implementation conforms to CTI 4501 for that category; and

- Ensure that all the requirements identified for CTI 4501 conformance testing are verified by the verification activities.

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Section 8.4 provides an overview of the different types of documentation, their relationships among each other, and the importance of test document. Each requirement to be verified is traced to a verification (test) case, which then can be traced to the appropriate stage(s) in the verification (test) procedures. A verification case is a logical grouping of communications interface and performance requirements that are to be verified together.

The RTCTM in Table 7 identifies an initial list of example test cases to be performed for CTI 4501 conformance testing for MAP messages. To confirm that an implementation fulfills a requirement, the implementation under test shall successfully pass all test cases that trace to that requirement. Collectively, the test cases in the RTCTM all must be successfully performed to claim conformance with CTI 4501.

The RTCTM contains the following information:

- Requirement No. The identifier of the requirement that is being verified by the test case.
- Requirement. A short description of the requirement.
- Test Case Identifier. A unique identifier for the test case(s).
- Test Case Name. A name for the test case(s).
- Verification Method. Identifies the method of verification to be used for the verification case. Valid values are Analysis, Demonstration, Inspection, and Test. The definitions for each method are:
    - Analysis. Verification of system using models, calculations, and testing equipment. This test method is used for a requirement that is fulfilled indirectly through a logical conclusion or mathematical analysis of a result. For example, algorithms for congestion: the designer may need to show that the requirement is met through the analysis of count and occupancy calculations in software or firmware.
    - Demonstration. Manipulation of the system to verify that the results are as planned or expected. This test method is used for a requirement that the system can demonstrate without external test equipment.
    - Inspection. Examination of the system using one of your five senses (auditory, olfactory, tactile, taste, visual). This test method is used for verification through a sensory comparison that the requirement has been satisfied. For example, the Vendor shall provide training on the troubleshooting of the system, including local intersection and central portions.
    - Test. Verification of system using a controlled and predefined series of inputs to ensure specific and predefined outputs are produced. This test method is used for a requirement that requires some external piece of test equipment (such as logic analyzer or voltmeter).
- Mandatory. Identifies if the requirement is mandatory to conform with CTI 4501. A 'Y' indicates that the requirement is mandatory and an implementation must successfully pass the test case(s) to claim conformance with CTI 4501. An 'N' indicates the requirement is optional, but if the test case is performed, the test case must still pass to be conformant to CTI 4501. An 'N/A' indicates the requirement is Not Applicable.

The requirements in Table 7 should be fulfilled to claim conformance to CTI 4501. The test cases referenced in Table 7 are examples of test cases. The test case details and activities may vary for each agency based on the agency's policies, test methodologies, and preferred test tools.

8.2.1 MAP Message Verification

MAP message verification for CTI 4501 consists of verifying that the MAP messages broadcasted from the RSU fulfill all the requirements identified in the RTCTM for MAP message verification (see Table 7).

Table 7 - RTCTM - MAP message verification

FR ID	Functional Requirement	Test Case Identifier	Test Case Name	Verification Method	Mandatory
6.3	Requirements				
6.3.1	Architectural Requirements				
CTI 4501: 6.3.1.1	LTEX-V2X Traffic Class Settings	TC-Radio-1	No Example Provided		Y
CTI 4501: 6.3.1.1.1.2	ProSe Per Packet Priority - MAP Message	TC-Radio-1	No Example Provided		Y
CTI 4501/3: 6.3.4.1.51	Protect V2X Radio Parameters	TC-Radio-1	No Example Provided		Y
6.3.3	Message Requirements				
6.3.3.1	Message Performance Requirements				
6.3.3.1.1	Uniform Message Requirements				
6.3.3.1.1.5	MAP Message - SAE J2735	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.1.6	MAP Message - Mandatory Data Elements	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.1.7	MAP Message - Required Data Elements	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.1.8	MAP Message PSID	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.3	Concise Messages Requirements				
6.3.3.1.3.1	Transport Message Size - WAVE	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.3.2	Concise MAP Message Requirements				
6.3.3.1.3.2.1	Nodes by Offsets	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.3.2.2	Computed Lanes Requirements				
6.3.3.1.3.2.2.1	Computed Lane - Lane Identifier	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.3.2.2.2	Computed Lane - X-Offset	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.3.2.2.3	Computed Lane - Y-Offset	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.3.2.2.4	Computed Lane - Angle	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y

FR ID	Functional Requirement	Test Case Identifier	Test Case Name	Verification Method	Mandatory
6.3.3.1.4	Advanced Notification Requirements				
CTI 4501: 6.3.3.1.4.1	Data Coverage - Every Ingress Lane	TC-Radio-2	No Example Provided		Y
CTI 4501: 6.3.3.1.4.2	Advanced Notification - Time	TC-Radio-2	No Example Provided		Y
6.3.3.1.5	Timeliness Requirements				
6.3.3.1.5.3	MAP Message - Broadcast Periodicity	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.1.6	Quality Assurance Requirements				
6.3.3.1.6.2	Completeness - MAP Message	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.2	Generic Message Requirements				
6.3.3.2.2	Message Revision Requirements				
6.3.3.2.2.3	MAP Message - Revision Counter Increment	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.2.2.4	MAP Message - Revision Counter Not Increment	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.2.2.5	MAP Message - Intersection Revision Counter Increment	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.2.2.6	MAP Message - Intersection Revision Counter Not Increment	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4	Roadway Geometry Data Requirements				
6.3.3.4.1	Intersection Geometry Requirements				
6.3.3.4.1.1	Intersection Geometry Information	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.2	Intersection Geometry - Road Authority Identifier	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.3	Intersection Geometry - Intersection Identifier	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.4	Intersection Reference Point Requirements				
6.3.3.4.1.4.1	Intersection Reference Point - Position	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.4.2	Intersection Reference Point - Description	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.5	Default Lane Width	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.6	Lane Identifier	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.7	Center of Vehicle Lane Geometry	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y

FR ID	Functional Requirement	Test Case Identifier	Test Case Name	Verification Method	Mandatory
6.3.3.4.1.8	Center of Crosswalk Geometry	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.9	Center of Pedestrian Landings Geometry	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.10	Lane Description	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.11	First Node Point - Ingress Vehicle Lane	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.12	First Node Point - Egress Vehicle Lane	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.13	Node Offset from Intersection Reference Point	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.14	Node Elevation Offset from Intersection Reference Point	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.15	Offset from Previous Node	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.16	Elevation Offset from Previous Node	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.17	Advanced Notification - Ingress Vehicle Lane	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.18	End Nodes - Crosswalk Lane	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.19	End Nodes - Pedestrian Landing	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.20	Maximum Distance between Nodes	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.21	Maximum Number of Nodes	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.22	Node Lane Width	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.1.23	Node Lane Width Change	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2	Lane Attributes				
6.3.3.4.2.1	Direction of Travel	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2.2	Lane Sharing	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2.3	Lane Type Attributes	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y

FR ID	Functional Requirement	Test Case Identifier	Test Case Name	Verification Method	Mandatory
6.3.3.4.2.4	Lane Attributes - Vehicle	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2.5	Lane Attributes - Crosswalk	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2.6	Lane Attributes - Bicycle	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2.7	Lane Attributes - Tracked Vehicles	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.2.8	Lane Attributes - Parking	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.3	Lane Maneuvers	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.4	Connections between Lanes				
6.3.3.4.4.1	Lane Connections	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.4.2	Connection Egress Lane	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.4.3	Connection Maneuvers	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.4.4	Connection Signal Group	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.4.5	Include Only Permitted Connections	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.5	Speed Limit Information Requirements				
6.3.3.4.5.1	Default Speed Limit	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y
6.3.3.4.5.2	Change in Lane Speed Limit	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	N
6.3.3.4.6	Revocable Lanes	TC-MAP-Data-Capture-1	MAP Data Capture 1- Message Structure and Content. See Table 9.	Analysis	Y

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FR ID	Functional Requirement	Test Case Identifier	Test Case Name	Verification Method	Mandatory
6.3.3.4.7	Signal Timing and Roadway Geometry Information Synchronization				
6.3.3.4.7.1	Matching SPaT and MAP Version	SPaT-MAP-Data-Consistency-1	SPaT-MAP Data Consistency. Refer to CTI 4501/1 Table 11, Example Test Case - SPaT-MAP Data Consistency.	Analysis	C(2)
6.3.3.4.7.2	Matching Intersection Reference Identifiers	SPaT-MAP-Data-Consistency-1	SPaT-MAP Data Consistency. Refer to CTI 4501/1 Table 11, Example Test Case - SPaT-MAP Data Consistency.	Analysis	C(2)
6.3.3.4.7.3(1)	Complete List of Signal Group Identifiers	SPaT-MAP-Data-Consistency-1	SPaT-MAP Data Consistency. Refer to CTI 4501/1 Table 11, Example Test Case - SPaT-MAP Data Consistency.	Analysis	C(2)
6.3.3.4.7.4(1)	Matching Signal Group Identifier Movements	SPaT-MAP-Data-Consistency-1	SPaT-MAP Data Consistency. Refer to CTI 4501/1 Table 11, Example Test Case - SPaT-MAP Data Consistency.	Analysis	C(2)
6.3.4	Security Requirements				
6.3.4.1	Data Trustworthiness: Sources and Processing	TC-Security-1	No Example Provided		Y
6.3.4.2	Data Communications Security	TC-Security-1	No Example Provided		Y
6.3.4.8	MAP Message Contents Trustworthiness	TC-Security-1	No Example Provided		Y
6.3.4.10	Consistency Between MAP and SPaT Messages	TC-Security-1	No Example Provided		C(2)
6.3.4.11.3	Correctness of MAP Availability Indications	TC-Security-1	No Example Provided		Y
6.3.4.11.4	Correctness of MAP Unavailability Indications	TC-Security-1	No Example Provided		Y
6.3.4.12	Intersection Identifier Trustworthiness	TC-Security-1	No Example Provided		Y
CTI 4501/3: 6.3.4.17.1	Prevent Change in Radio Coverage	TC-Radio-2	No Example Provided		Y
CTI 4501/3: 6.3.4.17.2	Detect Change in Radio Coverage	TC-Radio-2	No Example Provided		Y
CTI 4501/3: 6.3.4.17.3	Prevent Change in Radio Power	TC-Radio-2	No Example Provided		Y
CTI 4501/3: 6.3.4.17.4	Detect Change in Radio Power	TC-Radio-2	No Example Provided		Y
CTI 4501/3: 6.3.4.18	CI Security Verification Requirements	TC-Security-2	No Example Provided		Y

(1) Added in CTI 4501 v02.

(2) If SPaT Messages are also broadcasted.

8.3 Planned Activities

A verification plan must describe the activities to verify that a system fulfills the requirement. In this context, the verification plan describes the activities to test if a connected intersection conforms to CTI 4501. This section presents some example test methodology concepts, example approaches to testing and conformance, and example test environments.

Refer to 8.3 in CTI 4501/4 for information on verification plans.

8.3.1 CTI 4501 Conformance Testing by Stage - MAP Messages

Table 8 represents an example of when a subset of CTI 4501 conformance testing for MAP messages may be performed or repeated during the different stages of a connected intersection's life cycle.

Table 8 - Verification by stage - MAP message

Stage	Test Scope
Component Testing	Applicable per device-level certification
Integration Testing	Perform all test cases for all mandatory and selected requirements
Integration Testing - Field	Minimally perform the test cases for a subset of mandatory and selected requirements
System Testing	Perform the test cases for a subset of mandatory and selected requirements
Burn-in Testing	Perform the test cases for a subset of mandatory and selected requirements
Operations and Maintenance	Perform a subset of SAE J3238/2 after changes to firmware or hardware

8.3.2 Test Methodology - MAP Messages

This section contains examples of test cases for verifying MAP messages for conformance to CTI 4501. Refer to SAE J3238/2, which describes an alternate testing and verifying methodology to verify the accuracy of MAP message node points using LiDAR based mobile mapping data.

8.3.2.1 MAP Test Case

The test case described here was used to validate the MAP messages during a validation phase of CTI 4501 v01, which took place between April and September of 2021. The findings from performing this test case are found in CTI 4502. The test case has been updated to reference the current version of CTI 4501 and SAE J2735 as of the publication date.

Figure 14 is an illustration identifying the relevant data flows used in the CI MAP Message Level Test Cases.

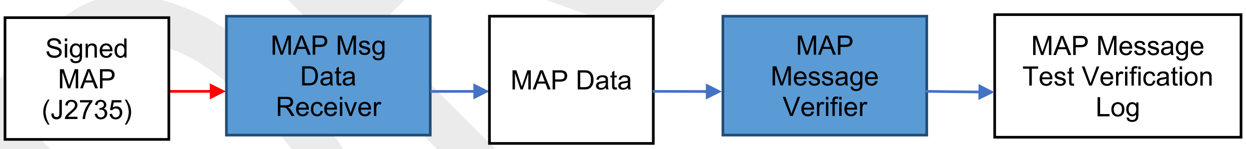

Figure 14 - CI MAP message data structure and content test case diagram

The Intersection Geometry Information sent to RSU will be verified as an output of the RSU, as captured by the MAP Msg Data Receiver. The input Intersection Geometry Information sent to the RSU will not be tested. Whether the RSU has valid certificates will not be tested in this test case.

Table 9 - Example test case - MAP data capture

Test Case	
ID: TC-MAP-Data-Capture-1	MAP Data Capture - Message Structure and Content
Purpose:	Verify format, message content values, and structure of MAP data stream output from RSU are correct per SAE J2735_202309(1) and CTI 4501.
Objective:	Verify system interface between an RSU and RSU Message Receiver. The test case verifies that the MAP message broadcast from the RSU contains all the mandatory objects, and that the objects conform with the valid value ranges as specified in SAE J2735_202309(1) and CTI 4501.
Inputs:	Table 3 contains a complete MAP Data specification.
Expected Outcome(s):	All MAP data and message structure are verified as correct, including: structure of data, and valid value of data content with respect to the valid value ranges as specified in SAE J2735_202309 and CTI 4501.
Feature Pass/Fail Criteria:	All mandatory MAP data elements within the message are verified as correct. Message structure of MAP is correct. Fail: Any other outcome.
Preconditions:	The MAP is validly signed, either by the RSU or by a center node as discussed above. Every device (RSU) is certified prior to testing.

(1) Updated from SAE J2735_202007 to SAE J2735_202309.

SAE J3238/2 also describes methods to verify several MAP message requirements, including:

- 6.3.3.4.1.5 - Default Lane Width
- 6.3.3.4.1.7 - Center of Vehicle Lane Geometry
- 6.3.3.4.1.11 - First Node Point - Ingress Vehicle Lane
- 6.3.3.4.1.12 - First Node Point - Egress Vehicle Lane
- 6.3.3.4.1.17 - Advance Notification - Ingress Vehicle Lane
- 6.3.3.4.1.20 - Maximum Distance Between Nodes
- 6.3.3.4.1.22 - Node Lane Width

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8.3.2.2 CI SPaT-MAP Data Consistency Test Case

The test case described here was used to verify that the intersection identifier in the SPaT and MAP messages for the same intersection is the same. This test case was used during a validation phase of CTI 4501 v01, which took place between April and September of 2021. The findings from performing this test case are found in CTI 4502. The test case has been updated to reference the current version of CTI 4501 and SAE J2735 as of the publication date. Figure 15 is an illustration identifying the relevant data flows used in the CI SPaT-MAP Data Consistency Message Level Test Cases.

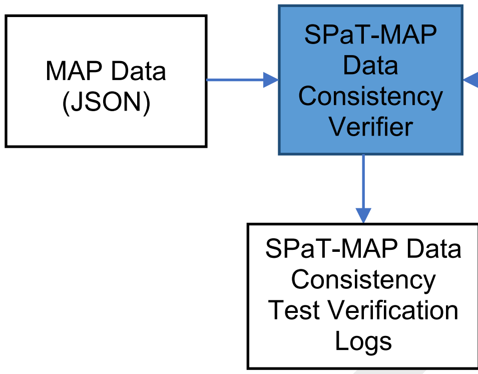

Figure 15 - CI SPaT-MAP data consistency test case diagram

8.3.3 Test Environment

A verification plan needs to describe the test environment to provide a basis for comprehensive and consistent testing. Refer to CTI 4501/4, 8.3.5, Test Environment, for an example on how to describe the test environment.

8.4 Test Documentation

Refer to CTI 4501/4, 8.4, Test Documentation, for a description of the different types of test documentation that should be developed for testing and validation.

9. NOTES

9.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY SAE CONNECTED TRANSPORTATION INTEROPERABILITY COMMITTEE

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ANNEX A - SECURITY PROFILES [NORMATIVE]

This annex shows the IEEE Std 1609.2 security profiles and related material for an SAE J2735 MAP message sent from the RSU to OBUs/MUs.

An implementation, such as an RSU, may have a separate security certificate for each security profile, i.e., have separate security certificate for each message; or may have a security certificate that contains security profile for more than one V2X message or V2X application.

A.1 SECURITY PROFILE FOR MAP MESSAGES

This section addresses the following topics:

- Identification of application message constraints and usage of application-sensitive SAE J2735 MAP message fields
- IEEE Std 1609.2 certificate Service Specific Permissions (SSP) required to permit sensitive application activities
- IEEE Std 1609.2 security profile for message sending, receiving, and security management

A.1.1 Summary

A security summary of the application is provided in Table A1.

Table A1 - MAP application security summary

V2I Application/Message	MAP
PSID	0x20-40-97
Certificate Type	IEEE Std 1609.2 Application Certificate
Message Signer	MAP generator and signer
Message Sender	RSU
Message Receiver	OBU
Entity Activities Requiring Authorization	One entity-activity requiring authorization within this application is: • Communicate Speed Limits for either intersection or road segments • State conformance with RLVW performance requirements

A.1.2 MAP PDU Field Use and Convention

This section imposes additional rules, definitions, and constraints on the MAP message PDU defined in SAE J2735.

A.1.2.1 Communication of Regulatory Speed in the PDU

The MAP message allows for the following two different topology types in which regulatory speed may be communicated:

- One for intersections: MAP.intersections.[IntersectionGeometry].speedLimits
- One for road segments: MAP.roadSegments.[RoadSegment].speedLimits

Population of either of these fields with a type of regulatory speed implies an authorized regulatory agency has performed analysis to provide a static or adaptive speed limit appropriate for the intersection or roadway geometry. Thus, the authorization needed is the right to communicate a regulator's authorized speed.

A.1.2.2 Indication That the MAP Sender Is Verified as Able to Be in Conformance with the Requirements for RLVW

An intersection that sends MAPs may be in one of three states:

- Operated by an operator who is capable of validating that the intersection meets the requirements to send messages suitable for RLVW, and currently meeting those requirements.
- Operated by an operator who is capable of validating that the intersection meets the requirements to send messages suitable for RLVW, and not currently meeting those requirements.
- Operated by an operator who does not intend to send messages suitable for RLVW, and so not meeting those requirements.

If an intersection that is not qualified for RLVW use sends MAPs that could be read as indicating that an RLVW is about to occur, it could cause receiving vehicles to take incorrect actions such as raising an incorrect alert to the driver, annoying the driver and possibly causing them to disregard future messages. Therefore, it is important to distinguish between intersections that are capable of meeting the RLVW requirements and intersections that are not.

A.1.3 Security Specific Permissions [Normative]

This section provides the Service Specific Permissions (SSP) format for the MAP application.

SSP type: IEEE Std 1609.2-2022 BitmapSsp

SSP length: 2-Octets

Bit Order: Most Significant Bit (MSB) is transmitted first

Encoding: Canonical Octet Encoding Rules (COER)

Table A2 indicates the MAP SSP octet scheme:

Table A2 - SSP octet scheme

Octet(s)	Definition
0	SSP Version Information Binary 0 (0000 0000): This version (0), a temporary use SSP Binary 1..255: SSP Version
1	See Table A3
2-30	Reserved for future use. Absent in current use.

Table A3 indicates the SSP roles and authorizations for the MAP application message.

Table A3 - MAP service-specific permissions

Octet	Bit	Application Activity Authorizations	Value
1	0	*MAP.roadSegments.[RoadSegment].speedLimits* or *MAP.intersections.[IntersectionGeometry].speedLimits* has an entry Message sender authorized to indicate regulatory speed.	0: Certificate may not sign 1: Certificate may sign
1	1	Intersection operator is authorized to set the *Conformant With 2024 RLVW Requirements* bit	0: Certificate may not sign 1: Certificate may sign
1	2-7	Reserved	0

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A.1.3.1 SSP Usage

This section provides conventions for utilizing the MAP application message.

A.1.3.1.1 Sending MAP Messages

The MAP message sender shall sign the PDU with an IEEE Std 1609.2 certificate indicating the signer is authorized to send a MAP PDU, i.e., certificate contains the MAP PSID.

If the SSP associated with the MAP PSID is present, then Octet 0 shall be (in binary) 0000 0001 (version 1, the version of this SSP).

If the MAP PDU also includes any regulatory speed information for the intersection, i.e., If the MAP message includes an entry in the MAP.roadSegments.[RoadSegment].speedLimits or MAP.intersections.[IntersectionGeometry].speedLimits fields, then the signer shall sign the MAP with a certificate whose SSP Octet 1, Bit 0 is set to 1 for the SSP associated with the MAP PSID.

A MAP message could involve indicating a regulatory speed for a road segment or intersection.

A.1.3.1.2 Validating MAP Messages

Upon receiving the MAP message, the message receiver [OBU] carries out IEEE Std 1609.2 validation. This includes checking that the signing certificate contains the MAP PSID.

If the SSP associated with the MAP PSID is present, the message is invalid unless the SSP version is 1 (Octet 0 of the SSP is, in binary, 0000 0001).

If regulatory speed information is included, the message is invalid unless the SSP Octet 1, Bit 0 is set to 1.

A.1.4 IEEE Std 1609.2 Security Profile Identification [Normative]

Table A4 provides the security profile identification features for MAP messages signed by authorized central traffic management systems and broadcast by RSUs.

Table A4 - MAP broadcast application security profile identification

Name	Recommended Values	Notes
Security Profile Version	IEEE Std 1609.2-2025	
Name	"MAP Security Profile_SAE_V1"	
PSIDs	0x20-40-97	
Information Flows	The application contains only one V2X information flow and this security profile addresses that flow.	
SDEE Role	Only one role in the application, MAP Signer	
Other considerations	None	

A.1.5 Sending

Table A5 provides the security profile for message sending within the MAP PSID.

Table A5 - MAP application security profile for sending messages

Name	Recommended Values	Notes
Sign Data	TRUE	The information flow requires integrity and authorization.
Signed Data Payload Types	"Encapsulated Data"	Including the signed data in the payload makes processing easier and does not add overhead.
HeaderInfo: Include Generation Time	TRUE	Since PDUs in the information flow are re-signed, generation time should be included.
HeaderInfo: Include Generation Location	FALSE	Relevance location is conveyed by the payload.
Geographic Information Type	Point or Area	May describe a single intersection based on a single reference point or multiple intersections.
HeaderInfo: Include Expiry	TRUE	This message is signed, stored, and repeatedly transmitted, AND periodically resigned for freshness (when the PDU content has not changed). It is therefore possible that the situation described by the message will change while the message is still cryptographically valid. In this case an attacker could retransmit the older message and it would be believed by receivers. Including an expiry time limits the time during which an attacker could carry out this attack.
HeaderInfo:Lifetime for Expiry	Default to one week but may be changed	
Signer Identifier Types	"Certificate / digest"	SPDUs are to be signed with a certificate, not with a raw public key.
Signer Identifier: Minimum Inter CertTime	Always	Certificate is attached when the MAP is signed and the whole packet with attached certificate is rebroadcast by the RSU.
Signer Identifier: Additional	None	
Signer Identifier Type Self: Source for Verification Key	N/A	Signer type self is not allowed.
Sign With Fast Verification	Compressed	This is the convention for SAE applications.
EC Point Format	Compressed	This is the convention for SAE applications.
Encrypt Data	No	
PDU Functional Types	Application PDU	
Carrying SDEE for Asserted Data	False	No asserted data is included.
Repeat Signed SPDUs	TRUE	The SPDU is to be re-signed after a certain period of time.
Time Between Signing	Default to one week but may be changed	
Send Operating Organization ID	In certificate only	Intersection identifier is combination of Operating Organization ID in certificate plus <DE_RelativeRoadAuthorityID> (optional) plus <DE_IntersectionID> (required) from the payload.
Signer Identifier: Certificates to Attach	1	Attach one certificate only, that of the signer.
p2pcd flavor	Out of band	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.
p2pcd_maxResponseBackoff	.25 second	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.
p2pcd_responseActiveTimeout	.25 second	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.
p2pcd_requestActiveTimeout	.25 second	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.
p2pcd_observed-RequestTimeout	.25 second	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.
p2pcd_currentlyUsed-TriggerCertificateTime	1 minute	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.
p2pcd_response-CountThreshold	3	Convention for SAE applications – refer to SAE J2945/1 and SAE J3161/1.

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A.1.6 Receiving

Table A6 provides the message reception security features for the MAP application security profile.

Table A6 - MAP application security profile for receiving messages

Name	Recommended Values	Notes
Use Preprocessing	TRUE	Needed for any information flow that receives signed SPDUs.
Verify Data	TRUE	The information flow requires integrity and authorization.
Source of PSID from Context	WSMP Header	The MAP is sent over WSMP and the PSID in the WSMP header must be identical to the PSID in the 1609.2 HeaderInfo.
Generation Time Source	Payload	dDateTime is used in the payload so there is no need to obtain the generation time from the security headers.
Expiry Time Source	Security Headers	See *HeaderInfo: Include Expiry*.
Relevance: Replay	FALSE	The message is intended to be replayed.
Relevance: Generation Time in Past	FALSE	Generation Time need not be checked for being "recent enough" because Expiry Time is also included.
Relevance: Generation Time in Past: Tolerance	N/A	
Relevance: Generation Time in Future	FALSE	The receiver is assumed to have its own means for handling skew between participants rather than delegating this to the security services. It is recommended that the receiver discards a MAP with a generation time .5 second or more in the future but this is not mandatory.
Relevance: Generation Time in Future: Tolerance	N/A	
Relevance: Expiry Time	TRUE	Messages received after their expiry time should be ignored.
Relevance: Location	FALSE	The receiver is assumed to have its own means for handling messages from too far away to be of interest.
Relevance: Generation Location: Tolerance	N/A	
Identified Region Representation Accuracy	10 minutes	
Dubious Certificate Handling	Overdue CRL Tolerance	Convention
Overdue CRL Tolerance	30 days	
Relevance: Certificate Expiry	TRUE	The *IEEE Std 1609.2* security services will check if the signing certificate has expired as a condition of the validity of the message.
Consistency between Future Payload Data and Certificate	No	Assume the content is not with respect to a future time period for which certificate validity needs to be checked.
Accept Encrypted Data	No	Information flow is in plaintext.
Consistency: Operating Organization ID	FALSE	OpOrgId is to be included in the cert and provided to the receiving application but is not directly checked for consistency.

A.1.7 SECURITY MANAGEMENT

Table A7 provides the security management features for the MAP application security profile.

Table A7 - MAP application security management security profile

Name	Recommended Values	Notes
Signing Key Algorithm	ecdsaNistP256withSha256	Convention for SAE applications.
Encryption Algorithm	N/A	Information flow is in plaintext.
Implicit or Explicit Certificates	IMPLICIT	Convention for SAE applications.
EC Point Format: Certificates	COMPRESSED	Compressed elliptic curve point formatting reduces total message size.
Non-global Geographic Validity in Certificate	Optional	Certificate may contain geographic constraints but this is optional.
Supported Geographic Region Types	"All"	Convention for SAE applications.
Maximum Full Certificate Chain - Length	4	
CertificateId Type	"Name" or "Binary ID"	
Use Individual Linkage ID	No	Certificates are individually revoked.
Use Group Linkage ID	No	
Additional CertificateId Constraints	None	

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ANNEX B - ADDITIONAL INFORMATION

B.1 SAE J2735 MAP MESSAGE DATA STRUCTURE

The CTI 4501 family of documents defines the minimum requirements to support RLVW applications. Thus, Table 3 lists the data frames and data elements that are mandatory or conditionally mandatory to be supported for nationwide interoperability for RLVW applications. Developers of RLVW applications should expect that these data frames and data elements will be provided in MAP messages that are conformant to CTI 4501.

Table 3 does not include those data frames or data elements that are optional – that is, should not be expected to be included in MAP messages for RLVW applications. These data frames and data elements may be mandatory to be provided in broadcasted MAP messages for other V2X applications, but that is outside the scope of CTI 4501.

Table B1 lists the data frames and data elements that are included in the MAP messages as defined in SAE J2735. To minimize the size of this table, additional child data frames and data elements below and optional data frame are not listed in the table. For example, roadSegments=DF_RoadSegmentList is an optional data frame for SAE J2735 and CTI 4501, thus any child data frames or data elements that comprise roadSegments are not presented in Table B1.

The "SAE J2735 Mandatory" column indicates if the data frame or data element is mandatory to describe the roadway geometry for an intersection as defined in SAE J2735. A value of M indicates that the data frame or data element is mandatory to be included in every MAP message. A value of O indicates that the data frame or data element is optional and does not have to be included in every MAP message broadcasted. O.# (range) notation indicates that the data frame/element is part of an option group (#), and is used to show a set of selectable options. Support of the number of items indicated by the '(range)' is required from all options labeled with the same numeral #. A value of C indicates the data frame or data element is conditionally mandatory, meaning that the data frame or data element shall be broadcasted if certain conditions are met. The condition is also included in parentheses after the "C."

The "CTI 4501 Implementation" column indicates which data frames and data elements must be included in a broadcasted MAP message to conform with CTI 4501. A value of M indicates the data frame or data element must be included in every MAP message broadcasted. A value of C indicates the data frame or data element is conditionally mandatory, meaning that the data frame or data element shall be broadcasted if certain conditions are met. Three data elements in Table B1, region=RoadRegulatorID, fullRdAuthID=DE_FullRoadAuthorityID, and node-LatLon=DF_Node-LLmD-64b, are never used (sent) in a MAP message. The use of scaleXaxis=Scale-B12 and scaleYaxis=Scale-B12 data elements are not recommended at this time because there is no guidance at the time of publication on how these data elements are to be translated in an unambiguous manner.

NOTE: If there is any inconsistency between the values in Table 3 and Table B1, the values in Table 3 shall take precedence.

Table B1 - MAP Message Data Structure

SAE J2735 Data Frames and Data Elements	SAE J2735 Mandatory	CTI 4501 Implementation
messageId=DE_DSRCmsgID=18 (MAP UPER)	M	M
msgIssueRevision=DE_MsgCount	M	M
layerType=DE_LayerType	O	O
layerID=DE_LayerID	O	O
intersections=DF_IntersectionGeometryList=1 to 32 X DF_IntersectionGeometry	O	M
name=DescriptiveName	O	O
id=DF_IntersectionReferenceID	M	M
region=RoadRegulatorID	O	Not used
id=DE_IntersectionID	M	M
revision=DE_MsgCount	M	M
refPoint=DF_Position3D	M	M
lat=DE_Latitude	M	M
long=DE_Longitude	M	M
elevation=DE_Elevation	O	M
laneWidth=DE_LaneWidth	O	M
speedLimits=DF_SpeedLimitList=1 to 9 x DF_RegulatorySpeedLimit	O	M
type=DE_SpeedLimitType	C (if speedLimits is included)	M
speed=DE_Velocity	C (if speedLimits is included)	M
laneSet=DF_LaneList=1 to 255 X DF_GenericLane	M	M
laneID=DE_LaneID	M	M
name=DescriptiveName	O	O
ingressApproach=DE_ApproachID	O	O
egressApproach=DE_ApproachID	O	O
laneAttributes=DF_LaneAttributes	M	M
directionalUse=DE_LaneDirection	M	M
sharedWith=DE_LaneSharing	M	M
laneType=DF_LaneTypeAttributes=CHOICE	M	M
vehicle=DE_LaneAttributes-Vehicle	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.4)
crosswalk=DE_LaneAttributes-Crosswalk	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.5)
bikelane=DE_LaneAttributes-Bike	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.6)
sidewalk=DE_LaneAttributes-Sidewalk	O.1 (1..*)	O
median=DE_LaneAttributes-Barrier	O.1 (1..*)	O
striping=DE_LaneAttributes-Striping	O.1 (1..*)	O
trackedVehicle=DE_LaneAttributes-TrackedVehicle	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.7)
parking=DE_LaneAttributes-Parking	O.1 (1..*)	C (if data is included - see 6.3.3.4.2.8)
regional=RegionalExtension (Reg-LaneAttributes)	O	O
maneuvers=DE_AllowedManeuvers	O	M
nodeList=DF_NodeListXY=CHOICE	M	M
nodes= DF_NodeSetXY=2 to 63 X DF_NodeXY	M	M
delta=DF_NodeOffsetPointXY	M	M
node-XY1=DF_Node_XY_20b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B10	C (if node-XY1 is included)	C (if node-XY1 is included - see Section 6.3.3.4.1.15)
y=DE_Offset_B10	C (if node-XY1 is included)	C (if node-XY1 is included - see 6.3.3.4.1.15)

SAE J2735 Data Frames and Data Elements	SAE J2735 Mandatory	CTI 4501 Implementation
node-XY2=DF_Node_XY_22b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B11	C (if node-XY2 is included)	C (if node-XY2 is included - see 6.3.3.4.1.15)
y=DE_Offset_B11	C (if node-XY2 is included)	C (if node-XY2 is included - see 6.3.3.4.1.15)
node-XY3=DF_Node_XY_24b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B12	C (if node-XY3 is included)	C (if node-XY3 is included - see 6.3.3.4.1.15)
y=DE_Offset_B12	C (if node-XY3 is included)	C (if node-XY3 is included - see Section 6.3.3.4.1.15)
node-XY4=DF_Node_XY_26b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B13	C (if node-XY4 is included)	C (if node-XY4 is included - see 6.3.3.4.1.15)
y=DE_Offset_B13	C (if node-XY4 is included)	C (if node-XY4 is included - see 6.3.3.4.1.15)
node-XY5=DF_Node_XY_28b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B14	C (if node-XY5 is included)	C (if node-XY5 is included - see 6.3.3.4.1.15)
y=DE_Offset_B14	C (if node-XY5 is included)	C (if node-XY5 is included - see 6.3.3.4.1.15)
node-XY6=DF_Node_XY_32b	O.2 (1..*)	O.5 (1..*)
x=DE_Offset_B16	C (if node-XY6 is included)	C (if node-XY6 is included - see 6.3.3.4.1.15)
y=DE_Offset_B16	C (if node-XY6 is included)	C (if node-XY6 is included - see 6.3.3.4.1.15)
node-LatLon=DF_Node-LLmD-64b	O	Not used
regional=RegionalExtension (Reg-NodeOffsetPointXY)	O	O
attributes=DF_NodeAttributeSetXY	O	C (if data is included)
localNode=DF_NodeAttributeXYList=1 to 8 X DE_NodeAttributeXY	O	O
disabled=SegmentAttributeXYList=1 to 8 X DE_SegmentAttributeXY	O	O
enabled=SegmentAttributeXYList=1 to 8 X DE_SegmentAttributeXY	O	O
data=DF_LaneDataAttributeList=1 to 8 x DF_LaneDataAttribute	O	C (if data is included)
DF_LaneDataAttribute=CHOICE	O	C (if data is included)
pathEndPointAngle=DE_DeltaAngle	O	O
laneCrownPointCenter=DE_RoadwayCrownAngle	O	O
laneCrownPointLeft=DE_RoadwayCrownAngle	O	O
laneCrownPointRight=DE_RoadwayCrownAngle	O	O
laneAngle=DE_MergeDivergeNodeAngle	O	O
speedLimits=DF_SpeedLimitList=1 to 9 X DF_RegulatorySpeedLimit	O	C (if data is included - see 6.3.3.4.5.2)
type=DE_SpeedLimitType	C (if speedLimits is included)	C (if data is included - see 6.3.3.4.5.2)
speed=DE_Velocity	C (if speedLimits is included)	C (if data is included - see 6.3.3.4.5.2)
regional=RegionalExtension SIZE(1..4)	O	O
dWidth=DE_Offset_B10	O	C (if dWidth is included - see 6.3.3.4.1.22)

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SAE J2735 Data Frames and Data Elements	SAE J2735 Mandatory	CTI 4501 Implementation
dElevation=DE_Offset_B10	O	C (if dElevation is included - see 6.3.3.4.1.16)
regional=RegionalExtension (Reg-NodeAttributesSetXY)	O	O
computed=DF_ComputedLane	O	C (if computed is included - see 6.3.3.1.3.2.2)
referenceLaneId=DE_LaneID	C (if computed is selected)	C (if computed is included - see 6.3.3.1.3.2.2.1)
offsetXaxis=CHOICE	C (if computed is selected)	C (if computed is included - see 6.3.3.1.3.2.2.2)
small=DE_DrivenLineOffsetSmall	O.3 (1) (if computed is selected)	O.6 (1) (if computed is included - see 6.3.3.1.3.2.2.2)
large=DE_DrivenLineOffsetLarge	O.3 (1) (if computed is selected)	O.6 (1) (if computed is included - see 6.3.3.1.3.2.2.2)
offsetYaxis=CHOICE	C (if computed is selected)	C (if computed is included - see 6.3.3.1.3.2.2.3)
small=DE_DrivenLineOffsetSmall	O.4 (1) (if computed is selected)	O.7 (1) (if computed is included - see 6.3.3.1.3.2.2.3)
large=DE_DrivenLineOffsetLarge	O.4 (1) (if computed is selected)	O.7 (1) (if computed is included - see 6.3.3.1.3.2.2.3)
rotateXY=DE_Angle	O	O (if computed is included - see 6.3.3.1.3.2.2.4)
scaleXaxis=Scale-B12	O	Not recommended
scaleYaxis=Scale-B12	O	Not recommended
regional=RegionalExtension SIZE(1..4)	O	O
connectsTo=DF_ConnectsToList=1 to 16 X DF_Connection	O	M
connectingLane=DF_ConnectingLane	C (if connectsTo is selected)	M
lane=DE_LaneID	C (if connectsTo is selected)	M
maneuvers=DE_AllowedManeuver	O	M
remoteIntersection=DF_IntersectionReferenceID	O	O
signalGroup=DE_SignalGroupID	O	M
userClass=DF_RestrictionClassID	O	O
connectionID=DE_LaneConnectionID	O	O
overlay=DF_OverlayLaneList=1 to 5 X DE_LaneID	O	O
regional=RegionalExtension SIZE(1..4)	O	O
preemptPriorityData=DF_PreemptPriorityList=1 to 32 X DF_SignalControlZone	O	O
regional=RegionalExtension SIZE(1..4)	O	O
roadSegments=DF_RoadSegmentList=1 to 32 X DF_RoadSegment	O	O
dataParameters=DF_DataParameters	O	O
restrictionsList=DF_RestrictionClassList=1 to 254 X DF_RestrictionClassAssignment	O	O
regional=RegionalExtension SIZE(1..4)	O	O
roadAuthorityID=DF_RoadAuthorityID1=CHOICE	O	C (if a child organization exists - see 6.3.3.4.1.2)
fullRdAuthID=DE_FullRoadAuthorityID1	O	Not used
relRdAuthID=DE_RelativeRoadAuthorityID1	O	C (if a child organization exists - see 6.3.3.4.1.2)

DRAFT

ANNEX C - REVISIONS FROM CTI 4501 V01 [INFORMATIVE]

This annex identifies the changes that have been made to CTI 4501 related to MAP messages. The Technical Committee makes reasonable efforts to ensure that documents are as backward compatible as possible, but the primary purpose of these documents is to provide interoperability by developing recommended practices in a consensus environment. When changes are required to meet these objectives, the problematic elements, such as user needs, requirements, and design guidance, are refined (if the issue is primarily editorial) or deprecated and, in most cases, replaced with updated needs, requirements, and guidance. This annex identifies why each of these changes has been made.

C.1 UPDATES TO REQUIREMENTS

The following identify changes from CTI 4501 v01 to CTI 4501/2 for requirements.

C.1.1 Updated Road Regulator Requirements

Updated 3.3.3.4.1.2, Intersection Geometry - Road Regulator Identifier, and 3.3.3.4.8.1, Matching Intersection Reference Identifier, from CTI 4501 v01.

Refer to CTI 4501 Section A.1, Road Authority ID, for a detailed explanation and guidance.

Requirement 3.3.3.4.8.1, Matching Intersection Reference Identifier, from CTI 4501 v01 is replaced with 6.3.3.4.7.2, Matching Intersection Reference Identifiers.

C.1.2 Deprecated Intersection Reference Point Accuracy Requirement

Deprecated 3.3.3.4.1.4.3, Intersection Reference Point Accuracy, from CTI 4501 v01 because the accuracy requirement is already embedded into the requirement for the first node point position of each lane, which are physically verifiable locations. See 6.3.3.4.1.11 and 6.3.3.4.1.12.

C.1.3 Deprecated Node Accuracy Requirement

Deprecated 3.3.3.4.1.4.23, Node Accuracy, from CTI 4501 v01 because the accuracy requirement is already embedded into the requirement for the first node point position of each lane and the center of lane geometry requirements. See 6.3.3.4.1.7.

C.1.4 Deprecated MAP Message - Accuracy Requirement

Deprecated 3.3.3.4.7, MAP Message - Accuracy, from CTI 4501 v01 because the accuracy requirements are already embedded into requirements 6.3.3.4.1.7 to 6.3.3.4.1.12.