

Phase 1 System Design Document (SDD)

Vehicle-to-Everything (V2X) Accelerator: Connecting the West – Utah Department of Transportation

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Final Report – September 25, 2026
FHWA-JPO-26-018



U.S. Department of Transportation

Produced by Saving Lives with Connectivity: Accelerating V2X Deployment Grant
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology
U.S. Department of Transportation
Intelligent Transportation Systems Joint Program Office
Federal Highway Administration
Office of the Assistant Secretary for Research and Technology
Cover graphic source: U.S. Department of Transportation

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Technical Report Documentation Page

1. Report No. FHWA-JPO-26-018		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Phase 1 System Design Document (SDD) Vehicle-to-Everything (V2X) Accelerator: Connecting the West – Utah Department of Transportation				5. Report Date September 25, 2026	
				6. Performing Organization Code	
7. Author(s) D. Deeter, J. Schroeder, S. Zumpf, T. English, D. Weibler, L. Cordova, J. Amidon, L. Preisen, B. Leonard, and P. Castro				8. Performing Organization Report No.	
9. Performing Organization Name and Address Utah Department of Transportation 2060 South 2780 West Salt Lake City, UT 84104				10. Work Unit No. (TRAIS) Proj No F-ST99(1014)	
				11. Contract or Grant No. 693JJ324NF00003	
12. Sponsoring Agency Name and Address U.S. Department of Transportation ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590				13. Type of Report and Period Covered Final	
				14. Sponsoring Agency Code HOIT-1	
15. Supplementary Notes					
16. Abstract The System Design Document (SDD) was created for the Connecting the West (CTW) Program, which is part of the United States Department of Transportation's (USDOT) Saving Lives with Connectivity: Accelerating Vehicle-to-Everything (V2X) Deployment grant program. This SDD describes the detailed system design for the CTW Program. The report describes the overall system, with an emphasis on new system hardware and application components. The system described here was designed to meet user needs and functions described in the CTW Concept of Operations (ConOps) and the requirements enumerated in the CTW System Requirements (SyRS). The design is built upon the architecture described in the CTW System Architecture Document (SAD). This SDD provides traceability of requirements from user needs through design.					
17. Keywords V2X; Vehicle to Everything; Accelerator; Deployment; Intelligent Transportation Systems; System Design			18. Distribution Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 73	
				22. Price	

Acknowledgements

The Connecting the West (CTW) agencies and team members wish to acknowledge and memorialize the contributions of Tony English of Neaera Consulting, who passed away on June 16, 2025. We dedicate this System Design Document (SDD) to him. Tony was a long-time colleague and friend to many in the transportation industry. In particular, he provided invaluable contributions to this SSD, other CTW efforts, and the Vehicle-to-Everything (V2X) industry. His expertise was unparalleled. He worked tirelessly to advance transportation technologies and gave of his expertise freely. He supported important V2X efforts at the United States Department of Transportation (USDOT) and was a key contributor to efforts in Colorado and Wyoming. He had a specific passion for robotics; his high-school robotics team were champions at local and national competitions. Tony will be dearly missed.

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List of Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADS	Automated Driving System
API	Application Programming Interface
ARC-IT	National Intelligent Transportation System Reference Architecture
ATMS	Advanced Traffic Management System
BSM	Basic Safety Message
C-V2X	Cellular V2X
CAMP	Crash Avoidance Metrics Partnership
CDOT	Colorado Department of Transportation
CI	Connected Intersection
CIMMS	Connected Intersection Message Monitoring System
CIP	Comprehensive Installation Plan
CIPT	Connected Intersection Preferential Treatment
ConOps	Concept of Operations
COTS	Commercial Off the Shelf
CSW	Curve Speed Warning
CTI	Connected Transportation Interoperability
CTW	Connecting the West
CV	Connected Vehicle
CV PFS	Connected Vehicle Pooled Fund Study
DLT	Dead Letter Topic
DOT	Department of Transportation
FHWA	Federal Highway Administration
GeoJSON	Geographic JavaScript Object Notation
GLOSA	Green Light Optimal Speed Advisory
HMI	Human Machine Interface
HTTP(S)	Hypertext Transfer Protocol (Secure)
I2V	Infrastructure to Vehicle
ICD	Interface Control Document
IOO	Infrastructure Owner-Operator
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITIS	International Traveler Information System
ITS	Intelligent Transportation Systems
JSON	JavaScript Object Notation
LiDAR	Light Detection and Ranging
LTE	Long Term Evolution
LTS	Location and Time Service

MAP	Map Data Message
mTLS	Mutual Transport Layer Security
Ms	Millisecond
MUTCD	Manual on Uniform Traffic Control Devices
ngTMDD	Next Generation Traffic Management Data Dictionary
N/a	Not Applicable
NGTMDD	Next Generation Traffic Management Data Dictionary
NTRIP	Networked Transport of RTCM via Internet Protocol
OBU	On-board Unit
ODE	Operational Data Environment
OEM	Original Equipment Manufacturer
PKI	Public Key Infrastructure
PMEP	Performance Measurement and Evaluation Plan
REST	REpresentational State Transfer (REST)
RLVW	Red Light Violation Warning
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
RWIS	Road Weather Information Systems
SAD	System Architecture Document
SASL	Simple Authentication and Security Layer
SCM	Signal Command Module
SCMS	Security Credential Management System
SDD	System Design Document
SDSM	Sensor Data Sharing Message
SDX	Situation Data Exchange
SET-IT	Systems Engineering Tool for Intelligent Transportation
SI	Signalized Intersection
SMART	Strengthening Mobility and Revolutionizing Transportation
SNMP	Simple Network Management Protocol
SOI	System of Interest
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SSM	Signal Status Message
STP	System Test Plan
SWIW	Spot Weather Impact Warning
SyRS	System Requirements Specifications
TIM	Traveler Information Message
TLS	Transport Layer Security
TMC	Traffic Management Center
TOC	Traffic Operations Center

TRAC	Transportation Reports and Action Console
TSC	Traffic Signal Controller
TSCBM	Traffic Signal Controller Broadcast Message
TTC	Temporary Traffic Control
UAT	User Acceptance Testing
UDOT	Utah Department of Transportation
UML	Unified Modeling Language
UPER	Unaligned Packed Encoding Rules
USDOT	United States Department of Transportation
UTC	Coordinated Universal Time
V2I	Vehicle to Infrastructure
V2X	Vehicle-to-Everything
VRU	Vulnerable Road User
VSL	Variable Speed Limit
WTI	Wyoming Traveler Information
WYDOT	Wyoming Department of Transportation
WZDx	Work Zone Data Exchange

1. Introduction

This document is the System Design Document (SDD) for the Connecting the West (CTW) Program. The CTW Program is part of the United States Department of Transportation's (USDOT) Saving Lives with Connectivity: Accelerating Vehicle-to-Everything (V2X) Deployment grant program (often referred to as the V2X Accelerator program) aiming to showcase interoperable, large-scale V2X benefits to drive Original Equipment Manufacturer (OEM) investment. This document is a key step in the planning and design portion of the systems engineering approach for the program. The CTW Program is led by Utah Department of Transportation (UDOT) with partners Wyoming Department of Transportation (WYDOT) and Colorado Department of Transportation (CDOT). The CTW efforts will also include local agencies within each state, some of which will be partners in the process and others as participants. Each participating state has an existing connected vehicle ecosystem, and each state will expand and improve on this ecosystem through the CTW Program. However, as outlined below, these expansions and improvements are not uniform across all three states.

1.1. Purpose of the System Design Document

The SDD was created for the CTW Program and describes the detailed system design for the CTW Program by describing the new functions being added to the three existing CTW member states' systems.

The CTW Program was conceived to represent a model for how V2X systems will expand nationwide in a way that encourages V2X deployment while enabling V2X interoperability between states. Much like how V2X nationwide expansion is not expected to be accomplished by unifying systems together into one overarching nationwide system, the CTW Program is not creating a new CTW system nor is it unifying the three states' existing systems. Rather, the CTW Program consists of:

- Expansions of existing systems within CTW states, such as adding more field equipment in Utah and Colorado; adding more vehicle units in Utah; and expanding the use of Traveler Information Messages (TIMs) in Utah, Colorado, and Wyoming).
- The addition of new functions to exchange event reports and consistent TIMs between CTW states and with the wider community through dissemination to third-party traveler information providers. This SDD is focused on these new functions.

These expansions of existing functions and additions of new functions are intended to meet user needs and functions described in the CTW Concept of Operations (ConOps) and the requirements enumerated in the CTW System Requirements Specifications (SyRS). The Central Systems in each CTW state will continue to be managed separately, but as part of the CTW Program each Central System will exchange event reports and TIM messages through the Situation Data Exchange (SDX). As such, the CTW Program does not create a unified system between each state, although the messages used and exchanged between each CTW state will be consistent and follow available TIM standards. Given that the three states' systems will continue to operate independently to exchange standards-compliant messages, there is no configuration management needed between state systems.

Additional design elements in this SDD are included the Appendix, which includes an Interface Control Document (ICD) describing the CTW Central Systems' interfaces to the SDX.

This SDD does not include designs for existing systems or the geographic expansions of those systems. Rather, existing systems in each CTW state are described in the CTW ConOps. Expansions of those systems follow the same design. Additionally, external documentation is available from each state, as follows:

- UDOT existing systems are documented in a series of external UDOT Systems Engineering Documents, not published online. These documents include:
 - Systems Engineering Document for Connected Intersections.
 - Systems Engineering Document for Connected Roadways.
 - Systems Engineering Document for Vulnerable Road User (VRU) Safety at Connected Intersections (CIs).
- WYDOT existing systems are documented through [Wyoming CV Pilot documentation](#).
- CDOT existing systems are documented through local materials, including the V2X Technology, Safety, and Mobility Improvement; CDOT V2X BUILD Grant; and Systems Engineering Analysis.

The design is built upon the architecture described in the CTW System Architecture Document (SAD). This SDD provides traceability of requirements from user needs through design. The document is intended to describe the system design to stakeholders interested in design implementation details. The document may also be used as a resource by future deployments and state Departments of Transportation (DOTs) designing and deploying V2X systems.

1.2. Document Overview

This SDD contains the following sections and appendices:

- Section 2: System-Level Design Description.
- Section 3: Subsystems and Components Design.
- Section 4: Requirements Traceability Matrix.
- Appendix: Connecting the West – Situation Data Exchange (SDX) Interface Control Document (ICD).

1.3. Assumptions

A key assumption for this document is that CTW Program activities for the expansion of existing V2X legacy systems will be expanded with the original functionalities and specifications previously defined. In Wyoming, these functionalities were documented in the Wyoming Connected Vehicle (CV) Pilot. Updates and enhancements to the Operational Data Environment (ODE) that is used in both the Wyoming and Colorado Central Systems are included in the open source documentation for the ODE. Utah functionalities and requirements are documented in a series of UDOT Systems Engineering Documents for CIs, Connected Roadways, and Driver Warnings about VRUs at CIs.

Specifically, the CTW team will not build a new system from the ground up; it will expand existing deployments and operation of Field Equipment in Utah and Colorado and expand vehicle systems in Utah, with all of these continuing the functionality currently performed in these states and Wyoming. As such, for the expansion of legacy systems, the systems engineering process will not revisit or re-engineer these systems in this document. Therefore, the functions and physical systems of these legacy systems are described at a high level but not detailed in this SDD.

The CTW Program will add the functionality of each member state exchanging event messages and TIMs through the SDX in a consistent, interoperable manner, as described in Sections 3.1 and 3.2 as well as in CTW Traveler Information Message (TIM) Documentation Version 1.0, which is serving as input to a national standards effort led by USDOT . The Appendix of this document includes an ICD for the exchange of messages through the SDX.

For the event architecture approach for event messages, two key assumptions are made: First, that there is value in all event types being in a single, common data structure, and second, that there are an unknown number of data elements both for current event types and for new event types that may be identified in the future, yet there is a desire to accommodate these new data elements while minimizing breaking changes.

1.4. Constraints

As described in the CTW ConOps, the following constraints were identified by one or more of the following activities:

- **Needed Decisions or Actions** – Constraints identified during the user needs discussion and conceptualization of the system as items that are not CTW system requirements but need to be addressed in order for the system to function as intended.
- **Limitations to CTW Benefits** – Constraints to the benefits possible through operation of CTW systems outside control of the system.
- **Extracted from CTW Existing Systems Documentation** – Constraints extracted while documenting the existing systems that will remain operational.
- **External Influences** – Constraints that were identified based on national products or services available.

The constraints will either need to be addressed as part of the proposed system or as predetermined decisions later in the requirements, architecture, or design aspects of the CTW Program.

Constraints based on needed decisions or actions include:

- Success metrics and data to evaluate success will need to be defined for all deployed CTW systems.
- A public outreach campaign is needed to educate stakeholders in each CTW state about system benefits and to address any privacy concerns.
- A nationally accepted and trusted series of processes and procedures with supporting tools are needed by agencies operating CIs to support safety applications to determine if CIs are validated to ensure the trust of original equipment manufacturers (OEMs). (A solution for this constraint is being

developed through the UDOT “Verifying Connected Intersections” project as part of the USDOT Strengthening Mobility and Revolutionizing Transportation [SMART] Grants program.)

- A nationally accepted, common approach is needed to define how CIs validated to meet Connected Transportation Interoperability (CTI) requirements will be monitored to detect when the intersection data is not meeting “validated” status. (A solution for this constraint is being developed through the UDOT “Verifying Connected Intersections” project as part of the USDOT SMART Grants program.)
- There is a need for universal and consistent guidance on planning, design, and deployment of CIs, to guide consistent deployments that are interoperable with Security Credential Management System (SCMS) providers, On-board Units (OBUs), and Red Light Violation Warning (RLVW) applications. (This constraint is met through the “Connected Intersections Guidance Document” developed through the [Connected Vehicle Pooled Fund Study \[CV PFS\]](#).) Constraints resulting from this document include:
 - Requirements for CTW systems supporting CIs are constrained by CTI requirements, and as these are still evolving, the requirements will be referenced but not recreated in the CTW SyRS.
 - All CTW CI messages will be SAE J2735 messages.
- Each agency performing CI Preferential Treatment (CIPT) must have policies that define what vehicles are authorized to send CIPT requests and under what operating conditions they are authorized to request CIPT (e.g., bus occupancy, schedule adherence, and plowing in progress).
- Anticipated uses of data collected from CVs will need to be defined so CTW agencies can conduct useful performance management activities.
- Each agency will need to have defined and documented data retention policies to support data requests and uses of data to support CTW agency performance management.

Constraints causing limitations to CTW benefits include:

- The safety benefits that can be achieved through CI safety applications for SIs (e.g., RLVW applications) are constrained by the number of CIs that are currently deployed nationally, as the number of CIs influences the OEMs’ business decisions to release safety applications and the number of intersections for which warnings may be issued.
- The safety benefits of RLVW applications deployed by the CTW Program are further constrained by the number of privately owned vehicles equipped with the capability to receive RLVW messages.
- The safety benefits that can be achieved through safety applications on V2X Connected Roadways (e.g., to provide alerts and warnings pertaining to road weather conditions, work zones, curves, incidents, lane closures, and speed reductions) are constrained by the number of TIMs containing timely, accurate, and consistent information about hazards or events that are able to be generated and disseminated.
- The safety benefits of V2X Connected Roadways are further constrained by the number of public and privately owned vehicles equipped with the capabilities to generate and broadcast basic safety messages (BSMs) and receive TIMs.

Constraints based on information extracted from CTW existing systems documentation include:

- Any TIMs generated in the CTW Program will be constrained by existing data sources and data collected from BSMs broadcast in the vicinity of CTW member-operated Roadside Units (RSUs). No

additional data sources or field collection of data are being added through the CTW Program. This will constrain the types of TIMs that can be generated. Examples of these constraints include:

- TIMs describing the presence of workers in work zones are constrained to existing agency approaches for determining if workers are present.
- A local state Central System that issues and administers variable speed limits (VSLs) will be an external system and is needed for the CTW member to disseminate VSL messages. Any CTW agency that provides TIMs describing VSLs through the proposed CTW system will need to operate their local state Central System that is capable of calculating and authoritatively issuing VSLs based on approved business processes and making these VSLs available for the CTW Central System to access.
- CIs added in Utah to support CIPT will utilize the same approach where vehicles determine if they are authorized to request preferential treatment and only broadcast Signal Request Messages (SRMs) when appropriate.
- The distribution of TIMs to third-party traveler information system providers will be constrained by the successful implementation of the SDX in Wyoming. The SDX has an established (and growing) list of subscribers and a proven track record. This does not preclude any CTW member from pursuing additional data exchanges, but CTW Program efforts to exchange data to these third parties will use the SDX.
- WYDOT will continue communicating to vehicles using the Sirius XM radio approach, as this is a proven approach.

Constraints based on external influences include:

- The messages generated and broadcast by CTW subsystems to communicate alerts and traveler information is constrained by industry-available OBUs that currently support TIMs. Therefore, TIMs are designated as the SAE J2735 standard for communicating these messages.
- Long-term success of delivering TIMs to Commercial Off the Shelf (COTS) OBUs is constrained by the need for nationally consistent definitions of what, how, and when to create TIMs. (The CTW team is initiating the solution to this by facilitating discussions with additional states around common TIMs.)

1.5. Risks

Some technical risks related to the constraints are summarized as follows:

- **Crash Prevention at SIs** – The proposed CIs will have the potential to support RLVW applications that warn drivers who are about to run red lights at SIs. However, these benefits will be limited by the number of RLVW applications deployed to vehicles. But the number of intersections validated to meet minimum requirements for RLVW and the trust from OEMs and impacts on their decisions to deploy production vehicle applications can be measured.
- **VRU-Related Crash Preventions** – While the deployments of VRU safety systems at intersections hold great promise to reduce vehicle and VRU collisions, there is also the potential information overload to drivers. Monitoring vehicle movements will help to evaluate the impacts that the system has on driver behavior, and this will be a critical surrogate because it is impossible to accurately estimate the number of collisions avoided.

- **Crash Prevention Along Interstates and Rural Corridors** – The proposed system may not avoid an initial crash, but the system capabilities should be able to limit the extent of the crash (number of vehicles involved), related secondary crashes, and the severity of the crash (injuries/fatalities). These items are expected to be explored in the Performance Measurement and Evaluation Plan (PMEP), but the CTW team recognizes that it will not be possible to measure the impacts on crashes during the limited time period of this effort.
- **Information Overload** – System capabilities are limited by how much information can realistically be given to drivers. There is a multitude of possible information that could be provided including speed limits, warnings, incidents ahead, detours, parking opportunities, etc. Measuring the effectiveness of the eventual system will be a challenge and will be a topic during the development of the PMEP.
- **Technology Penetration** – The evaluation aspects of the CTW Program during the Federal Highway Administration (FHWA)-defined program's Phase 2 (Operate and Evaluate) will be challenged by the relatively few numbers of vehicles that will be capable of receiving direct information from the infrastructure or other vehicles, especially in comparison to the number of total vehicles operating in the project sites. The technology can be shown to work; however, measuring the benefits with such a small sample size will be limiting, although the coupled capabilities to also share messages with third-party traveler information applications will increase the number of drivers receiving alerts, albeit with increased latency.

1.6. Rationale for Key Decisions

The proposed system is being developed as part of a national program to accelerate V2X deployments. The approaches used by UDOT, WYDOT, and CDOT involve adherence to national standards and guidance documents on the interpretation of these standards whenever available. Therefore, the approaches being expanded are believed to be the best path forward for interoperability. However, the CTW team will continue to interface with the V2X Accelerator program sites and national industry if alternative approaches that are more conducive to interoperability surface.

2. System-Level Design Description

This section provides a description of the system, including context for the system, system capabilities, and system-level design.

As introduced originally in the CTW ConOps, Section 2.1 of the SDD provides the system context. The system capability changes in Section 2.2 of the SDD describe the expansions and changes planned through the CTW Program and include the following categories of changes:

1. Expansion of existing capabilities (i.e., existing capabilities that will be expanded with no change to the functionality). A high-level summary of expansions include:
 - a. Addition of 488 RSUs and supporting equipment at SIs in Utah, performing functions of currently deployed RSUs at intersections.
 - b. Addition of 222 RSUs and supporting equipment along interstates and rural corridors in Utah, performing the same functions of currently deployed RSUs along highways.
 - c. Addition of 220 OBUs and supporting equipment on transit buses and snowplows in Utah, performing the same functions of currently deployed OBUs.
 - d. Addition of 19 VRU warning systems-equipped intersections in Utah, performing the same functions of currently deployed VRU warning systems.
 - e. Addition of 42 RSUs and supporting equipment along I-70 in Colorado, performing the same function of current RSUs.
2. Capability changes (i.e., changes to existing conditions in terms of enhanced system capabilities and expanded deployments). A high-level summary of the capability changes include:
 - a. Interoperability of TIMs generated.
 - b. Addition of exchanges of event reports with other CTW states and through the SDX to third-party providers.
3. Personnel changes (i.e., changes to roles and responsibilities of CTW agency staff). Note that no additional staff are anticipated, and the majority of changes are the need to manage additional devices (e.g., Map Data Message [MAP] messages for additional intersections).

Finally, Section 2.3 of the SDD focuses on the areas where new capabilities are being developed (versus expansions of existing systems), which are the designs for TIM interoperability and event message interoperability between agencies.

2.1. System Context

The CTW system is the interface between the existing Central Systems in each CTW state. UDOT, WYDOT, and CDOT will continue to operate their individual Central Systems and Field Equipment while also continuing to operate fleet vehicles equipped with Cellular V2X (C-V2X) technologies. WYDOT will

also continue to operate fleet vehicles equipped with satellite-enabled V2X communications. The overall CTW System of Interest includes all these aspects as well as external systems supporting the CTW Program activities (e.g., traffic signal controllers [TSCs] and Traffic Operations Centers [TOCs]).

As such, the Central Systems in each CTW state will continue to be managed separately, but as part of CTW they will be supported by the SDX. The CTW Program does not create a unified system between each state, although the messages used and exchanged between each CTW state will be consistent and follow available TIM and Next Generation Traffic Management Data Dictionary (ngTMDD) standards.

Figure 1 shows the CTW system components by state and the linkages between them. It also illustrates that all system components already exist and are either being enhanced or expanded as part of the CTW Program, which is as follows.

- CDOT CTW Systems:
 - RSUs – Existing, CTW Expansions, No Functionality Change.
 - CDOT Operational Data Environment (ODE) – Existing, CTW Planned Enhancements.
 - Colorado CV Manager – Existing, CTW Planned Enhancements.
 - CDOT Fleet Vehicles – Existing, No CTW Enhancements.
 - Interfaces to external systems will include the following:
 - CDOT's Advanced Traffic Management System (ATMS).
 - Work Zone Reports.
 - SDX.
 - Private SCMS.
 - Location and Time Services (LTS).
- UDOT CTW Systems:
 - RSUs at SIs – Existing, CTW Expansions, No Functionality Change.
 - RSUs at C-V2X Connected Roadways – Existing, CTW Expansions, No Functionality Change.
 - Signal Command Module (SCM) – Existing, CTW Expansions, No Functionality Change.
 - C-V2X Central Systems – Existing, CTW Expansions, No Functionality Change.
 - Connected Intersections Message Monitoring System (CIMMS) – Existing, CTW Expansions, No Functionality Change.
 - LiDAR-Based VRU Detection Systems – Existing, CTW Expansions, No Functionality Change.
 - Blank-Out Signs – Existing, CTW Expansions, No Functionality Change.
 - CIPT Participating Vehicles (OBU-equipped) – Existing, CTW Expansions, No Functionality Change.
 - OBU-Equipped Fleet Vehicles – Existing, CTW Expansions, No Functionality Change.
 - Interfaces to external systems will include the following:
 - SDX.

- Private SCMS.
- Location and Time Services (LTS).
- Networked Transport of Radio Technical Commission for Maritime Services (RTCM) via Internet Protocol (NTRIP) RTCM Source.
- TSCs.
- UDOT ATMS.
- CIMMS.
- WYDOT CTW Systems:
 - RSUs – Existing, No CTW Enhancements.
 - The Wyoming Traveler Information System (WTI) – Existing, CTW Planned Enhancements.
 - The Wyoming ODE – Existing, CTW Planned Enhancements.
 - Wyoming CV Manager – Existing, CTW Planned Enhancements.
 - WYDOT Fleet Vehicles – Existing, No CTW Enhancements.
 - Interfaces to external systems will include the following:
 - SDX.
 - Private SCMS.
 - LTS.
 - Sirius XM Service.
 - Existing, No CTW Enhancements: UDOT ATMS and CIMMS.
 - Existing, CTW Expansions, No Functionality Change:
 - Field Equipment: SCM, VRU detection system, blank-out sign, RSUs at SIs, and RSUs on C-V2X Connected Roadways
 - Vehicle Systems: CIPT participating vehicles (transit, emergency vehicles, and snowplows) and OBU-equipped vehicles.
- CDOT CTW Systems:
 - Existing, No CTW Enhancements: CDOT ATMS, CDOT Work Zone Speed Reduction Reporting Forms, CDOT fleet vehicles, and CIMMS.
 - Existing, CTW Expansions, No Functionality Change: CDOT RSUs.
 - Existing, CTW Planned Enhancements: CDOT ODE and Colorado CV Manager.
- WYDOT CTW Systems:
 - Existing, No CTW Enhancements: WYDOT RSUs and WYDOT fleet vehicles.
 - Existing, CTW Planned Enhancements: WTI system, WYDOT ODE, and Wyoming CV Manager.
- External Systems:
 - Connection to only the UDOT CTW SOI: NTRIP RTCM source and TSC.
 - Connection to only the WYDOT CTW SOI: Sirius XM system.

- Connections to multiple state CTW SOIs:
 - SDX: UDOT (has a planned CTW Program change) and CDOT, with a connection to SDX subscribers.
 - SCMS: UDOT, CDOT, and WYDOT.
 - LTS: UDOT, CDOT, and WYDOT.

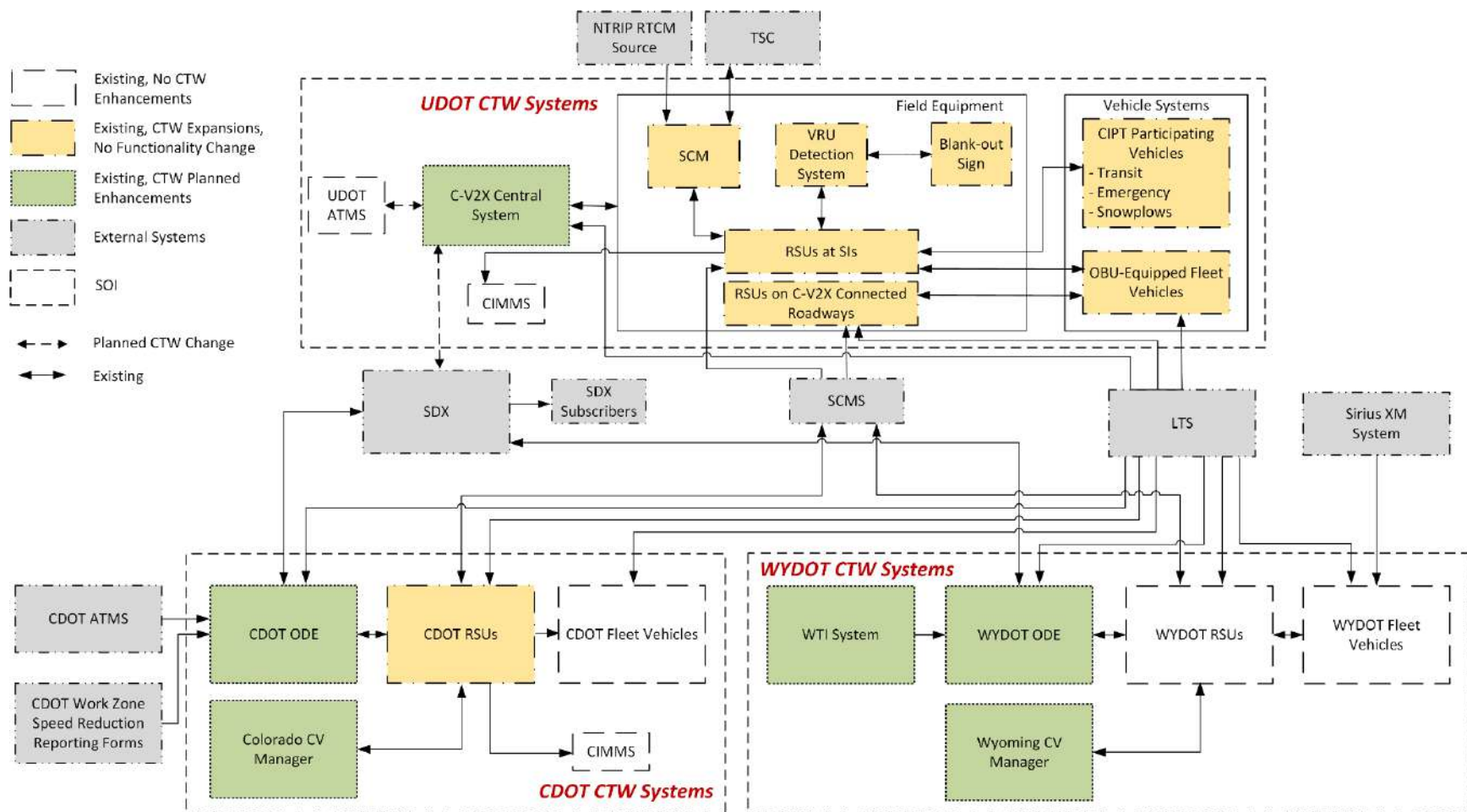


Figure 1. CTW System
Source: Athey Creek Consultants, February 2026

2.2. System Capabilities

The following describes the anticipated changes within each category introduced above:

1. **Expansion of Existing Capabilities** – The following expansions of existing functions will be performed by the CTW Program:
 - a. *Expand preferential treatment at CIs.* Expand CI preferential treatment for transit and emergency vehicles and snowplows to additional intersections and vehicles in Utah.
 - b. *Add more CIs.* Expand the number of SIs in Utah that operate as CIs and meet the accuracy, reliability, and timeliness parameters needed to support in-vehicle safety applications to address the user needs to the extent possible.
 - c. *Expand the number of RSUs broadcasting and receiving messages.* Expand the deployments of RSUs to broadcast TIMs and receive BSMs in Utah and Colorado.
 - d. *Expand VRU detection and alerts at intersections.* Deploy systems at a limited number of intersections in Utah to further test and demonstrate capabilities to detect VRUs crossing intersections and provide alerts to drivers about possible conflicts with vehicles.
 - e. *Expand system monitoring and reporting.* Expand and enhance the collection, storage, and management of data describing the health of systems and messages exchanged with equipped vehicles.
 - f. *Expand security credentialing.* Expand the processes of attaching security credentials to messages exchanged by additional Field Equipment and Vehicle Systems.
 - g. *Demonstrate OEM vehicle interoperability.* Involve a C-V2X-enabled OEM vehicle with safety applications as a public agency-operated test vehicle with available safety applications and drive a predetermined, instrumented “loop” corridor within the three CTW states.
 - h. *Expand integration of CV data.* Expand the ingest, quality-check, and processing of data from CVs in Colorado and Utah as the number of RSU data collection sites expand.
 - i. *Expand data storage.* Expand data storage processes to support additional RSU data collection sites.
2. **Capability Changes** – The proposed system will accomplish the following capability changes:
 - a. *Improve TIM consistency.* Modify the approaches used in CTW states for generating and managing TIMs to achieve consistency in message structure and content.
 - b. *Increase and improve TIM creation.* Expand the capability to create TIM messages (using the consistency approach agreed upon) that describe Spot Weather Impact Warning (SWIW), Curve Speed Warning (CSW), alerts, and advisories by increasing the geographic coverage and expanding message content creation in Utah, Wyoming, and Colorado.
 - c. *Improve consistency of Interstate exchange of event reports.* Modify event report creation in each state to a consistent approach and exchange event reports describing traveler information alerts among the CTW states using the SDX.
 - d. *Create new TIM exchanges.* Utilize the SDX such that each CTW state sends TIMs and receives TIMs from neighboring states.

- e. Demonstrate SCMS interoperability. Conduct demonstrations to understand the extent to which SCMS certifications are interoperable between the CTW states and take steps to achieve interoperability as needed.
 - f. *Refine SCMS certificates without cellular service.* Refine and expand an approach to topping off SCMS certificates in Utah fleet vehicles that does not require cellular service.
3. **Personnel Changes** – No new personnel are expected to be added as a result of the proposed system, but roles and responsibilities of staff may change:
- a. *Manage additional MAP messages.* In Utah, staff and/or contractors will be responsible for creating and managing additional MAP messages.
 - b. *Maintain additional Field Equipment.* In Colorado and Utah, staff will be responsible for maintaining new Field Equipment added as part of this effort.
 - c. *Maintain additional Vehicle Systems.* In Utah, staff will be responsible for maintaining equipment on fleet vehicles that support C-V2X connectivity.
 - d. *Manage additional TIMs and TIM interoperability.* In all CTW states, staff will need to manage the creation, update, and removal of TIMs to ensure they convey the maximum information possible to travelers and adhere to interoperability standards and best practices.
 - e. *Manage expanded data.* In each CTW state, staff will be responsible for managing data retention and access.

2.3. System-Level Design Approach

As noted above, the CTW Program will accomplish three areas of change, as follows:

1. Expansion of existing capabilities (i.e., existing capabilities that will be expanded with no change to the functionality).
2. Capability changes (i.e., changes to existing conditions in terms of enhanced system capabilities and expanded deployments).
3. Personnel changes (i.e., changes to roles and responsibilities of CTW agency staff).

The approach to the system-level design is described as follows:

- **Not Focus on Expansions** – The system-level design will not focus on the expansion of existing capabilities. These expansions will occur as originally described in the CTW Concept of Operations (and stated above under anticipated changes in Section 2.2), and will be expansions of successfully operating systems, including aspects related to mounting equipment, power sources, and connections to fiber connections, as done throughout the system.
- **Focus on Capability Changes** – The system-level design will focus on those changes where enhanced system capabilities are to be performed, with emphasis on new capabilities. Note that many of the requirements defined in the SyRS will be accomplished by configurations of existing systems and are not covered in this SDD.
- **Not Focus on Personnel Changes** – As this SDD defines the system design, personnel changes will not be included.

The emphasis of the system-level design will be to focus on those areas identified during the development of the SyRS. Specifically, there were areas identified where the requirements specifically called out design decisions to be made during design phase. These areas will be the focus of the system design and include:

- **TIM Interoperability Design** – This design aspect will primarily impact the CTW Central Systems as these subsystems create and manage TIMs. This will also impact the CTW Vehicle Systems as these subsystems receive, process, and display the TIMs. However, as COTS OBUs are the primary Vehicle Systems, there are limitations on design and customization that is possible. While the CTW Field Equipment will be receiving the TIMs from Central Systems and broadcasting for Vehicle Systems, the Field Equipment are not expected to change their role of forwarding messages given the changes to the structure and content of TIMs.
- **Event Message Interoperability Design** – This design aspect will also primarily impact the CTW Central Systems as they add the functions to create and send event reports in an interoperable way and to receive, process, and use event reports from neighboring states in creation of local TIMs. This will not impact the Vehicle Systems, as these systems do not receive event reports directly.
- **System Design Interoperability through Conformance with the Connected Transportation Interoperability 4501 (CTI 4501) Implementation Guide** – This design aspect will describe existing systems and CTW-added tools and interfaces that will be used to meet the guidance.

Each of these designs will be described in sections below.

3. Subsystems and Components Design

As described in Section 2.1, the CTW system is the interface between the existing Central Systems in each CTW state. The CTW system design includes information describing TIM interoperability design and event message interoperability design. In the CTW design, Central Systems continue to be independently managed by each CTW Program agency but will exchange standardized and interoperable TIMs and event messages via the supporting SDX. Note that configuration management is not in the scope of the CTW Program effort, and additional details about possible changes to the TIMs during operations will be described in subsequent documentation for the maintenance and operations phase. Additional information about the CTW system interface with the SDX is included in the ICD (Appendix).

3.1. TIM Interoperability Design

Each of the CTW partner states currently delivers messages to Vehicle Systems using TIMs. While each state creates TIMs that adhere to SAE J2735 standards, the standards have areas that are optional and/or open to interpretation. As a result, the three CTW states do not specifically create TIMs using the same approach. Looking broader across the industry, in order for COTS OBUs to all receive, process, and display information communicated as TIMs consistently, there is a need for interoperability in TIM creation, update, and deletion. As a result of this, consistency in the development of TIMs is paramount to the success and national interoperability of the delivery of warnings, alerts, and other information through TIMs.

As part of the design process, the CTW team (specifically Trihydro) has led a design process to define design guidelines for the creation and exchange of TIMs that will accomplish interoperability and unambiguity in the use of TIMs across the three CTW states and, ultimately, nationwide. These interoperability guidelines, if followed, will enable Central Systems across the United States to create consistent and interoperable TIMs and enable Vehicle System OBUs to be developed that can receive these and present appropriate messages to drivers. Any changes to these TIMs to resolve identified issues, as well as new TIMs created, during the maintenance and operations phase of the CTW Program will undergo a similar design process to ensure national interoperability.

Additional TIM design decisions are included in the following documents that were also developed by the CTW team and are compiled in a CTW Traveler Information Message (TIM) Documentation Version 1.0 resource, which is serving as input to a national standards effort led by USDOT:

- Use of the TravelerInformation Structure to Build Standard Traveler Information Messages. A document developed by the CTW team that describes the data elements of the SAE J2735 TIM structure and how these data elements are projected to be used for TIMs generated for the CTW effort.
- Detailed Traveler Information Message Definitions. Documentation (in progress) still being developed by the CTW team of detailed definitions for each of the TIMs prioritized for development as a part of the CTW effort for interoperable use.

- **Traveler Information Message Summary Table.** A summary table developed by the CTW team to describe the content and conditions for the initial TIMs prioritized and developed as a part of the CTW Program effort for interoperable use.

Guidelines regarding the design for Central Systems of TIMs are presented in the subsections below for Central Systems and Vehicle Systems. Note that the following assumptions were made about the roles and responsibilities of the Infrastructure Owner-Operators (IOOs) and the vehicle on-board systems regarding TIM use and implications:

- Assumptions that represent design context that the SDD relies on but does not enforce include:
 - While the CTW Program agencies will have control over how TIMs are used for displaying messages to drivers for the CTW deployment, in the long term at a national level with OEM vehicles, the IOO cannot control and does not intend to dictate how the data provided in the TIMs are used. The IOO does not assume responsibility for how the data is interpreted or acted upon.
 - In-vehicle alerts may be visual, auditory, haptic, or any combination of the three. The nature of the alert may vary based on the vehicle make and model, driver-controlled settings, or the alert type.
 - The content, timing, and delivery location of the TIMs from the IOO are intended to elicit device reactions, resulting in consistent driver information across IOO boundaries.
 - Messages may be sent via RSU, from a cloud-based service, over a cellular data connection, via satellite, or by other means of wireless communications. Different delivery methods may be used in different locations; different delivery methods may or may not be available for the same location.
 - The messages may be consumed by third-party navigation systems, interpreted, and processed into customized navigation/travel updates. Subscribers to the third-party navigation systems may then receive navigation/travel updates that incorporate data from multiple TIMs but do not necessarily contain the exact information from each TIM.
 - Messages may be intermittently unavailable due to maintenance or unplanned outages. If the TIMs are not available, drivers should rely on existing roadway communication means, such as roadside signage, dynamic message signs, and traffic control devices.
- Assumptions that are normative requirements (rules that CTW Program participating IOOs agree to follow) include:
 - The TIMs will adhere to data quality checks currently being developed by the industry. This will help ensure the accuracy and timeliness of the data provided to the vehicle.
 - IOO deployment of TIMs may be performed by the IOO, may be integrated into construction contracts as an obligation of the contractor, or may be delegated by the IOO to a third party. For the purposes of this SDD, the IOO is assumed to have final authority over messages created on their behalf.
 - All TIMs include location information, typically a geofence extent that defines the area of relevance for the TIM. This information will allow in-vehicle calculations regarding the vehicle location relative to the event location of the indicated warning. The geofence extent will vary depending on the TIM and is described in each TIM definition.
 - The TIM source will be authenticated using the appropriate authentication mechanism for the selected message delivery method. For direct vehicle to infrastructure (V2I) delivery, this would entail the use of the SCMS to sign the message.

- TIMs in this document were designed to work with vehicle on-board systems with a Level 1 message receiver capability (see Section 3.1.4).

3.1.1. Central System TIM Creation and Exchange Design

To meet the requirements defined for CTW central systems interfacing to each other, the Central Systems in each CTW state are existing systems and are not being designed or developed, but rather will be configured to perform the following actions:

- The Central Systems in each CTW state will create SAE J2735 TIMs when appropriate.
 - There is no set frequency of the creation of TIMs, and they will be created when conditions merit they be created, using defined thresholds within each state.
 - Each CTW state will create TIMs for their selected roads throughout their state and not limit the TIM creation to just locations of RSUs (as TIM-sharing to the SDX will deliver TIMs to all subscribers to the SDX including third-party navigation systems).
 - The Central Systems in each CTW state will process information from local sources (e.g., event reports, Advanced Traffic Management System [ATMS] outputs, BSMs from vehicles, and other sources) to generate the TIMs.
 - The TIMs created will be as defined in J2735 standards in one of the following versions: 2016, 2020, or 2024
- The Central Systems in each CTW state will update and expire TIMs.
 - There is no set frequency for updates or expirations of TIMs. The Central Systems will process data examining conditions and information and updated and expired TIMs as appropriate.
- The Central Systems in each CTW state will send TIMs to the appropriate RSU for broadcast as they are created, updated, and expired.
 - TIMs will be sent to the appropriate RSU after creation and sent again whenever they are updated. When expired, the Central System will remove TIMs from the RSU.
- The Central Systems in each CTW state will send TIMs to the SDX as they are created, updated, or expired.
 - The Central Systems will send TIMs to the SDX within 1 minute after the TIM is created.
 - The Central Systems will send updated TIMs to the SDX within 1 minute after the updated TIM is created.
 - The Central Systems will send TIM expirations to the SDX within 1 minute after the TIM expiration.
 - The Central Systems will interface to the SDX to send each TIM and receive confirmation that the TIM is received. Until such time that confirmation is received, the system will continue to send the TIM.
- The Central Systems in each CTW state will download TIMs from the SDX.

- The Central Systems will connect to the SDX and download TIMs based on a geographic boundary query (i.e., specifying the geographic boundary or boundaries) that is of interest and at a frequency that is determined by the state downloading the TIM.
- Central Systems will be capable of processing J2735 TIM messages in all of the following versions: 2016, 2020, and 2024.
- The Central Systems may send TIMs received from the SDX to one or more of their RSUs for broadcast. The decisions of which TIMs that are downloaded from the SDX to send to RSUs will be local decisions made by each CTW state.

3.1.2. Central System TIM Interoperability Design

The TIM guidelines developed as a part of this CTW Program effort provide definitions for generating standardized CV TIMs, which are in a separate CTW Traveler Information Message (TIM) Documentation Version 1.0 resource, which is serving as input to a national standards effort led by USDOT. The capabilities of the CTW central systems will use the developed guidelines when automatically generating TIMs. The CTW Vehicle System OBUs will follow the guidelines developed to the extent possible, recognizing that COTS OBUs are being procured. The intent of this guidance is to support IOOs in developing their TIM generation systems with the goal of providing consistent messaging to the driver/vehicles operating across the United States roadway network.

This TIM guide provides operational guidance related to multiple service packages defined in the National Intelligence Transportation System Reference Architecture (ARC-IT). Many of the ARC-IT service packages include “driver information” and/or “vehicle signage data” information flows. This TIM generation guidance directly supports these information flows by providing clear definitions for specific messages to be delivered to drivers and vehicles. These common definitions allow all parties to correctly interpret messages and relate them to roadway events and conditions.

Within this guide, some TIM elements are rigorously defined to ensure that all consumers can unambiguously interpret the message. Other elements are more loosely defined to allow flexibility across IOOs regarding how and when they generate a given TIM. Each TIM definition in the CTW Traveler Information Message (TIM) Documentation Version 1.0 includes four sections:

1. **Conditions** – This section roughly describes the conditions that would prompt the generation of a given TIM. Responsible IOOs will likely want to refine these condition descriptions to more closely align with their operations. The conditions may also describe constraints when a particular TIM should not be used.
2. **Message** – This section defines the exact International Traveler Information System (ITIS) phrases to apply for each TIM. The phrases identified for each TIM should not be altered. Using a consistent message phrase for each TIM is critical, as it enables unambiguous interpretation of each message. Some messages have parameters as part of the message phrase, allowing variable values to be incorporated into the message (e.g., a numeric value for a speed limit).

A “suggested driver display icon” is also included in the message section for each TIM. These display icons, based on the Manual on Uniform Traffic Control Devices (MUTCD) signage, are considered the fastest way for drivers to visually comprehend a TIM. Many of the icons are exact replicas of MUTCD signage, while others follow the MUTCD color and shape conventions for different types of signage. These are suggested visual displays for the driver; on-board systems

that provide visual displays for driver alerts may develop other more effective visual representations.

3. **Geofence Extent** – This section defines how the geofence, indicating the “area of relevance” of a given TIM, should be constructed. This area of relevance is where the IOO has determined that the message is highly relevant for drivers/vehicles on the roadway. Some elements of the geofence are flexible and may be determined by individual IOO operational rules. However, there are geofence elements that are very tightly constrained to ensure a common understanding of roadway locations associated with the message.
4. **Timing** – This section describes constraints that may apply to the start and end times of a given TIM. For example, the end time of a road construction TIM must accurately match the time when the associated road work is complete and the work zone is cleared from the roadway.

3.1.3. Field Equipment TIM Interoperability Design

The capabilities of the CTW Field Equipment added through the CTW Program will be based on systems engineering documentation developed by CDOT and UDOT outside the CTW Program effort. These capability designs will be supplemented by the following decisions reached by CTW team members during the requirements phase of this project:

- **Field Equipment Receipt of TIMs** – Field Equipment in Utah and Colorado that is added through the CTW Program will be configured to include capability of receiving J2735 TIMs in 2016, 2020, and 2024 versions.
- **Field Equipment Broadcast TIMs** – Field Equipment in Utah and Colorado that is added through the CTW Program will be configured to include capability of broadcasting TIMs in J2735 Version 2024.

3.1.4. Vehicle System TIM Interoperability Design for On-Board Message Receiver Capability

An important consideration in defining a TIM is the capability of the vehicle on-board systems to interpret and use the message information. To explain this concept, three levels of on-board systems capability were defined, as shown in Table 1. These levels outline the different capabilities of on-board systems to use the messages. The different capability levels have different implications for generating TIMs, so these considerations are outlined for each capability level in Table 1.

Table 1. On-Board Unit Levels and Respective Message Receiver Capabilities*Source: Trihydro, April 2025*

Level	Name	Function Description	Considerations Generating TIMs
1	Basic Message Processing	- Reads content, location, and timing from TIM. - Provides a driver alert when the vehicle is located within the defined geofence, vehicle heading is within defined bounds, and time is within defined active time. - Alerts with the information found in the message content (per ITIS codes).	- The number of simultaneous messages delivered within an area must be considered to avoid driver alert overload. - Upstream geofence extents must be defined considering advanced warning time for drivers.
2	Enhanced Message Processing	- Reads content, location, and timing from TIM. - Generally, provides a driver alert per the TIM-defined geofence, but may adjust the alert area considering vehicle-specific information such as speed. - Active time of the TIM is always respected. - Provides a driver alert based on the content of the message but potentially altering the alert for better relevance for the vehicle/driver (e.g., adding distance countdown, not showing a reduced speed if driver is already at or below TIM speed limit, or not showing a TIM that is restricted to a different vehicle class than the host). - May implement smart alert filtering to avoid overloading driver with multiple simultaneous alerts.	- The number of simultaneous messages delivered within an area must be considered to avoid driver alert overload. - Upstream geofence extents must be defined considering advanced warning time for drivers.

Level	Name	Function Description	Considerations Generating TIMs
3	Vehicle Integrated Message Processing	• Reads content, location, and timing from TIM. • May use the TIM to generate a driver alert, and/or the data may be input to systems supporting vehicle operation and navigation. • May not display TIM information in situations where it is not needed or appropriate (e.g., not displaying an advisory speed if the vehicle is already under the advisory speed). • May display supporting information to the driver (e.g., a summary of the distance ahead that the work zone is in operation). • TIM-defined geofence primarily provides location data for the defined event. If a driver alert is generated, the geofence may be used to indicate where to provide a driver alert although the alert area may be modified based on vehicle-specific data. • Determines type of alert to deliver to the vehicle/driver based on the content of the message but potentially altering the alert for better relevance for the vehicle/driver.	• Accuracy of location and timing information is more critical as it may be used by driver assist systems and/or navigation systems. • Geofences can be focused on the roadway event location, as on-board calculations will determine advanced alert distances if necessary.

Most CV OBU available in 2025 are at Level 1 capability. There may be some that implement one or two of the Level 2 capabilities, but no currently available OBUs reach the Level 3 capability. CTW team members have had (and will continue) discussions with OBU manufacturers about their devices' abilities to perform Level 2 capabilities, but a migration of OBUs to Level 2 capabilities will be a decision of OBU manufacturers and is not a factor the CTW team can control. Instead, the TIM design described here provides information about the content needed to target and support OBUs with different levels of capabilities.

However, delivery through third-party navigation systems may provide some Level 3 capabilities. In the CTW Program, the SDX and detailed TIM definitions described in the CTW Traveler Information Message (TIM) Documentation Version 1.0, which is serving as input to a national standards effort led by USDOT, facilitate Level 3 capability by providing access to the messages to existing third-party applications (e.g., Google Maps) that may integrate the messages into navigation and routing messages. For example, if a third-party system identifies a road closed TIM, they may use this information to generate new routes to navigate around the road closure and deliver those new navigation plans to their affected subscribers. These on-board system capability levels are separate from the automated driving system (ADS) capability

definitions in SAE J3016. However, the on-board receiver capability of Level 3 that is defined here implies integration of the TIM data with higher-level ADS.

3.2. Event Message Interoperability Design

The CTW Systems Engineering documentation describes the functionality to be added so that each CTW agency will create event report messages describing current hazards, incidents, work zones, or other conditions that possibly merit the creation of TIMs for dissemination through the CTW subsystems. Each CTW agency will create these event reports and send them to the SDX for delivery to other CTW members.

Ideally, these event reports would follow a consistent, national approach towards formatting and content creation. The CTW team will use the Institute of Transportation Engineers (ITE) Next Generation Traffic Management Data Dictionary (ngTMDD) document that is currently in a stable draft format as the event structure to be used for the CTW Program. This decision recognizes that the ngTMDD may still change slightly but is believed to be the best approach for scaled expansion to exchanges with other states.

When considering traffic events, there are many different types, some of which require unique consideration. Weather events, for example, while clearly impacting the roadway, are different than vehicle-based events (e.g. crash, stalled vehicle, etc.), with each type consisting of different data elements, areas of effect, timeliness factors, and more. Due to the inherently different nature of event types, certain sensors or data sources may be optimized for detection of different categories of events. For example, a construction event might be manually recorded vs. an automatically detected weather event. The approach and planned use of the ngTMDD is an architectural approach to events that fundamentally separates event detection and event message generation from TIM generation in order to uncouple event input data elements from output requirements and provide the flexibility a robust scalable system demands. Figure 2 illustrates this concept by identifying key components of each CTW state's Central System. Events can then be converted into TIMs for the given event type, as described in Section 3.1.

The architecture for event message generation includes the following (see also Figure 2):

- Data sources that are inputs for generating event reports and TIMs:
 - Road Weather Information Systems (RWIS)
 - V2X data (Rich BSMs)
 - Vehicle telematics data (Utah only)
 - Work Zone Data Exchange (WZDx)
 - Other future data sources
- Many systems receive event reports and TIMs and also provide data that can be used to generate new event reports and TIMs, as part of an exchange of standardized traffic events and driver warnings, such as the following:
 - SDX
 - VSLs

- ATMS
- Other systems
- Event reports and TIMs are used to automatically configure TIMs on RSUs.

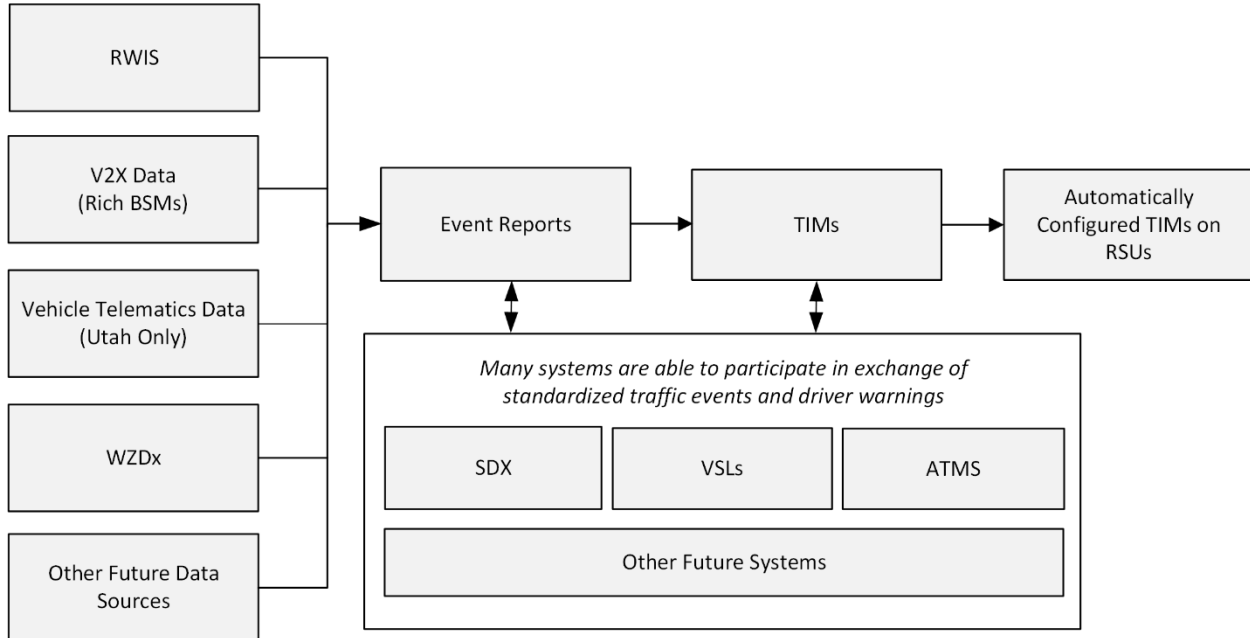


Figure 2. Architecture for Event Message Generation

Source: Panasonic, April 2025; modified for legibility and removed specifics of the UDOT system (i.e., Cirrus) by Athey Creek Consultants, December 2025

3.2.1. Central System Event Message Creation and Exchange Design

To meet the requirements defined for CTW central systems interfacing to each other, the Central Systems in each CTW state are existing systems and are not being designed or developed, but rather will be configured to perform the following actions:

- The Central Systems in each CTW state will create event messages when appropriate.
 - There is no set frequency of the creation of event reports, and they will be created when conditions merit creating one, using defined thresholds within each state.
 - Each CTW state will create event reports for their selected roads throughout their state and not limit the event report creation to just locations of RSUs.
 - The Central Systems in each CTW state will process information from local sources (e.g., event reports, ATMS system outputs, BSMs from vehicles, and other sources) to generate the event reports.
 - The event reports created will be as they are defined in the ngTMDD standard.
- The Central Systems in each CTW state will update and expire event reports.

- There is no set frequency for updates or expirations of event reports. The Central Systems will process data examining conditions and information and update and expire event reports as appropriate.
- The Central Systems in each CTW state will send event reports to the SDX as they are created, updated, or expired.
 - The Central Systems will send event reports to the SDX within 1 minute after the event report is created.
 - The Central Systems will send updated event reports to the SDX within 1 minute after the event report is updated.
 - The Central Systems will send event report expirations to the SDX within 1 minute after the event report expiration.
 - The Central Systems will interface to the SDX to send each event report and receive confirmation that the event report is received. Until such time that confirmation is received, the system will continue to send the event report.
- The Central Systems in each CTW state will download event reports from the SDX.
 - The Central Systems will connect to the SDX and download event reports based on a geographic boundary query (i.e., specifying the geographic boundary or boundaries) that is of interest.
 - Central Systems will be capable of processing ngTMDD event reports.
 - The Central Systems may use the event reports that are downloaded to create local TIMs to inform travelers within their state of events happening in neighboring states (e.g., to recommend a detour route). The decisions of which event reports that are downloaded from the SDX are used to generate TIMs will be local decisions made by each CTW state.

3.2.2. Central System Event Message Interoperability Design

There are two key assumptions used in this event architecture approach: First, there is value in all event types being in a single, common data structure, and second, there are an unknown number of data elements both for current event types and certainly for new event types that may be identified in the future, yet there is a desire to accommodate these new data elements while minimizing breaking changes.

Going deeper on the first assumption, reporting all traffic events in a unified structure provides several benefits. For example, it makes the architecture fundamentally scalable. If a single structure can accommodate all types, then adding a new type in the future does not break the architecture. SAE J2540 (ITIS Phrase Lists) contains thousands of varied potential event types, which is one indication of the amount of future scale possible and the value of being able to easily accommodate new types over time. In addition, a consolidated event reporting structure facilitates cross-type analyses and use cases, as mentioned above. Someone needing to know all events active in a location over a timeframe need only go to one place. If there are multiple real-time events in a single location, they can easily be identified and prioritized for downstream applications like generating TIMs.

Please refer to the [ngTMDD EventInformationResponse object](#) for the definition of the event information that will be shared between the states.

3.2.3. Field Equipment Event Message Interoperability Design

The interoperability design for event messages is not anticipated to have an impact on Field Equipment, and therefore no design is included for this subsystem.

3.2.4. Vehicle System Event Message Interoperability Design

The interoperability design for event messages is expected to have an impact on the Vehicle System, specifically on the OBU and human machine interface (HMI) that operates in the vehicle. In order that TIMs broadcast by all three partner agencies in the CTW Program are interpreted and display consistently in each state (and eventually nationwide), the CTW team is working with the OBU manufacturer, Commsignia, to document the configuration files that would be needed by the OBU to ensure that it successfully receives and processes the TIMs to recognize the ITIS codes and display the appropriate images and/or text on the HMI at the appropriate location. CTW team members are also coordinating with FHWA to include these configuration files, as appropriate, in future OBU standardization efforts so that all OBUs interpret TIMs consistently.

3.3. System Design Related to SCMS Management

3.3.1. SCMS Certificate Interoperability with Other States

The CTW states all procure SCMS certificates from authorized vendors who operate within the SCMS structure that is managed by SCMS Manager. It is important that vehicles owned by a public agency in one state with SCMS certificates are able to have the certificates recognized in other states, and for the Field Equipment and Central Systems in the other states to recognize these vehicles' SCMS credentials. The design aspects are as follows:

- Since all CTW state DOTs use a common SCMS provider, there is no anticipated issues with vehicles from one state DOT successfully achieving message exchanges with certificates in other states. System testing will verify this, and if it is not successful, CTW sites will work with the SCMS certificate supplier to resolve the issue.
- Outside of the CTW Program, UDOT has intentions of purchasing SCMS certificates from other SCMS vendors, but the timeline for this is not yet determined. As the use of SCMS certificates from multiple SCMS vendors has not been demonstrated before, little is known about whether additional vendor modifications will be needed to accomplish this. No CTW Program testing is planned, but UDOT will report results of the test.

3.4. System Design Related to Connected Intersection Conformance with the Connected Transportation Interoperability 4501 Standard

3.4.1. CTI 4501 Conformance Design Background

This section includes the CTW design related to conformance with the CTI 4501 Standard, specifically for signal phase and timing (SPaT) and MAP message creation and broadcast. The design for conformance related to SPaT and MAP messages in Utah (i.e., there are no CTW expansions of CIs in Colorado or Wyoming) are defined by two design aspects:

1. **Central System CTI 4501 Conformance Design** – Describes design aspects related to:
 - a. MAP message creation.
 - b. MAP message testing during Phase 1 system testing.
 - c. MAP message performance assessment during Phase 2 PMP evaluation activities.
2. **Field Equipment CTI 4501 Conformance Design** – Describes design aspects related to:
 - a. SPaT message generation and broadcast.
 - b. SPaT messages testing during Phase 1 system testing.
 - c. SPaT message performance assessment during Phase 2 PMP evaluation activities.

3.4.2. Central System CTI 4501 Conformance Design

The CTI 4501 conformance related to MAP message accuracy will be considered a Central System design aspect. The expansion of CIs in the CTW Program activities will follow UDOT's existing approach for creating and broadcasting MAP messages that follow SAE J2735 definitions and CTI 4501 requirements.

The CTW design to create MAP messages is described as follows:

- MAP messages will be created using industry tools and guidance materials. MAP messages will be created with input and clarifications from the CV PFS MAP Guidance document and using the FHWA MAP Creation Tool.
- MAP messages will be manually uploaded to the RSU. UDOT staff and contractors will manually upload MAP messages to the RSU for 'store and repeat' broadcasts.
- The RSU will broadcast MAP messages. Utah CIs will be equipped with OmniAir-certified RSUs that will broadcast the MAP messages at a frequency of 1 Hz.

The CTW design to support CTW System Test Plans (STPs) related to MAP messages executed during Phase 1 System Testing is as follows:

- Connected Intersection Message Monitoring System (CIMMS) will be the primary tool for testing MAP messages against CTI 4501 requirements. Approximately 10% of the Utah CIs added through CTW

will be connected to an operational instance of CIMMS to support testing of CTI-4501 messages validation during execution of the STPs.

- The instance of CIMMs running will be able to test the functional requirements as defined in Table 2 below.

Table 2. CTI 4501 Functional Requirements Related to MAP Messages to be Tested Using CIMMS as a Resource
Source: Neaera, February 2026

Functional Requirement ID	Functional Requirement	CIMMS Support	Notes
3.3.3.1.1.5	MAP Message - SAE J2735	Yes	n/a
3.3.3.1.1.6	MAP Message - Mandatory Data Elements	Yes	n/a
3.3.3.1.1.7	MAP Message - Required Data Elements	Yes	n/a
3.3.3.1.3.2.1	Nodes by Offsets	Partial	CIMMS can handle the various map data formats (offset XY, or explicit long-lat) but will not raise an event if the wrong one (verbose long-lats instead of offsets) is used.
3.3.3.1.3.2.2	Computed Lanes Requirements	Partial	CIMMS can handle the various map data formats (offsets, computed lane) but will not throw an error if the wrong encoding is used.
3.3.3.1.3.2.2.1	Computed Lane - Lane Identifier	Yes	n/a
3.3.3.1.3.2.2.2	Computed Lane - X-Offset	Yes	n/a
3.3.3.1.3.2.2.3	Computed Lane - Y-Offset	Yes	n/a
3.3.3.1.3.2.2.4	Computed Lane - Angle	Yes	n/a
3.3.3.1.4.1	Data Coverage - Every Lane	Yes	n/a
3.3.3.1.5.3	MAP Message - Broadcast Periodicity	Yes	n/a
3.3.3.1.6.2	Completeness - MAP Message	Yes	n/a
3.3.3.2.2.3	MAP Message - Revision Counter Increment	Yes	n/a
3.3.3.2.2.4	MAP Message - Revision Counter Not Increment	Yes	n/a

Functional Requirement ID	Functional Requirement	CIMMS Support	Notes
3.3.3.2.2.5	MAP Message - Intersection Revision Counter Increment	Yes	n/a
3.3.3.2.2.6	MAP Message - Intersection Revision Counter Not Increment	Yes	n/a
3.3.3.3.1.2	Road Regulator Identifier	Partial	CIMMS verifies that an ID is present and valid but cannot check if it is registered to the proper authority.
3.3.3.3.1.3	Intersection Reference Identifier	Yes	n/a
3.3.3.3.2.13	No MAP Available	Yes	Can be identified by observing missing MAP message forward.

The CTW design to support CTW performance measurement and evaluation of MAP messages as defined in the PMP is as follows:

- The MAP Test Tool developed by Camp Avoidance Metrics Partnership (CAMP) as part of the USDOT-funded Utah SMART Grant project between August 2023 and July 2025 will be one of the tools for ongoing performance assessments of MAP messages against CTI 4501 requirements. This tool was created in conjunction with the Utah SMART Grant project team that included SCMS Manager specifically to assess CI messages (both SPaT and MAP) against CTI 4501 requirements for the purpose of validating intersections that fully meet the CTI 4501 requirements. A selection of MAP messages developed in this project (currently defined as 5% of the intersections added through the CTW Program) will be uploaded and analyzed using the MAP Test Tool developed by CAMP and hosted by SCMS Manager.
- The MAP validation will verify that the MAP messages follow the SAE J2735 format and are complete. Visual inspection of the output will be conducted to identify any errors in connections.
- The CAMP MAP Test Tool will compare MAP message node points against known latitude and longitude points using an outside source (e.g., Light Detection and Ranging [LiDAR] scan data). By comparing initial node points for MAP messages to these known points, the performance of the MAP message node points will be understood and the MAP message node points will be corrected automatically by the CAMP MAP Test Tool until they are within the CTI 4501 accuracy levels.
- The CV PFS Test Plan describing manual field collection at CIs will be one of the tools for ongoing performance assessments of MAP messages against CTI 4501 requirements. The manual field collection and analysis of data conducted in the CV PFS project will be conducted for a selection of MAP messages developed in this project (currently defined as 5% of the intersections added through the CTW Program) during the PMP analysis to assess if MAP message accuracy is acceptable.
- The CIMMS installation used in system testing will remain operational. The CIMMS installation will continue to operate during the PEMP assessment period of Phase 2 to detect anomalies between vehicle movements and MAP data. CIMMS compares vehicle movements based on the BSMS

broadcast from vehicles moving through the intersection with MAP and SPaT data to identify potential errors or changes in MAP messages.

Exceptions to the functions defined for Central System CTI 4501 conformance design are described in Table 3.

Table 3. Exceptions to CTW Central System CTI 4501 Conformance Design

Source: Athey Creek Consultants, April 2025

Number	Exception to CTI 4501 Requirements	Reason/Justification
1	CTW members participating in CI validation will not validate the accuracy of all MAP messages using known locations of lane centerlines.	Currently, the cost of acquiring accurate reliable lane line (and derived lane centerline) positions is cost-prohibitive to validate the accuracy of all intersections. Similarly, manual field data collection is cost-prohibitive. Research and expanded testing through a UDOT-led SMART Grant is working to better understand the process and the percentage of intersections that agencies will need to validate.

3.4.3. Field Equipment CTI 4501 Conformance Design

The CTI 4501 conformance related to SPaT message accuracy and timeliness will be a Field Equipment design aspect. The expansion of CIs in the CTW Program activities will follow UDOT's existing approach for creating and broadcasting SPaT messages that follow SAE J2735 definitions and CTI 4501 requirements.

The CTW design to generate SPaT messages is described as follows:

- SPaT message content will originate from existing signal controllers that are operational at selected intersections in Utah. The signal controllers at selected intersections currently output the data that is required to formulate SPaT messages through an interface. These data are packaged into the Traffic Signal Controller Broadcast Message (TSCBM) and output at a periodicity of 10 messages every 1.0 second.
- Each CI will be equipped with a Signal Command Module (SCM). The SCM is a COTS product that performs multiple functions as the interface to the RSU. One function is to formulate SPaT messages that meet the CTI 4501 message structure.
- The SCM will formulate the SAE J2735 messages. As the signal controller outputs TSCBM messages, the SCM will receive each TSCBM message and create an SAE J2735 SPaT message that describes the current signal status with parameters defined by CTI 4501. UDOT is not designing the use of SCM through the CTW Program. The use of the SCM to meet CTI 4501 requirements was developed in earlier projects, and UDOT is expanding this proven approach in the CTW Program to additional sites. Exceptions to CTI 4501 that are not possible due to limitations caused by current signal controllers are described in Table 4.

- The SCM will send SPaT messages to the RSU. The SCM will deliver the SPaT messages to the RSU as an "immediate forward" message within 175 millisecond (ms) from the time the signal controller outputs the TSCBM. This process will repeat each 100 ms.
- The RSU will broadcast SPaT messages. Utah CIs will be equipped with OmniAir-certified RSUs that will broadcast the SPaT messages instantly.

While the goal is to meet CTI 4501 requirements, the CTW team recognizes that there are current CTI 4501 requirements that are not possible to be met with signal controller outputs available today. Ongoing discussions with the CTI 4501 group and SCMS Manager will continue to refine the requirements. Exceptions to CTI 4501 that are not possible due to limitations caused by current signal controllers (and will not be tested in the CTW STPs) are described in Table 5.

The CTW design to support the CTW STPs related to SPaT messages during Phase 1 system testing is as follows:

- CIMMS will be the primary tool for testing SPaT messages against CTI 4501 requirements. Approximately 10% of the Utah CIs added through CTW will be connected to an operational CIMMS installation.
- The instance of CIMMs running will be able to test the functional requirements as defined in Table 4.

Table 4. CTI 4501 Functional Requirements Related to SPaT Messages to be Tested Using CIMMS as a Resource

Source: Neaera, February 2026

Functional Requirement ID	Functional Requirement	CIMMS Support	Notes
3.3.3.1.1.1	SPaT Message - SAE J2735	Yes	N/a
3.3.3.1.1.2	SPaT Message - Mandatory Data Elements	Yes	N/a
3.3.3.1.1.3	SPaT Message - CI Mandatory Data Elements	Yes	N/a
3.3.3.1.5.1	SPaT Message - Broadcast Periodicity	Yes	N/a
3.3.3.1.5.2	SPaT Message - Broadcast Latency	Yes	N/a
3.3.3.1.6.1	Completeness - SPaT Message	Yes	N/a
3.3.3.2.1	Time Accuracy	Partial	The CIMMS system can check if timing information is significantly off but cannot verify the 10 ms range.
3.3.3.2.2.1	SPaT Message - Revision Counter Increment	Yes	N/a
3.3.3.2.2.2	SPaT Message - Revision Counter Not Increment	Yes	N/a

Functional Requirement ID	Functional Requirement	CIMMS Support	Notes
3.3.3.2.3.1	SPaT Message - Message Time Stamp	Yes	N/a
3.3.3.2.3.2	SPaT Message - Intersection Time Stamp	Yes	N/a
3.3.3.3.1.1	Intersection Signal Timing Information	Yes	N/a
3.3.3.3.2	Intersection Status Requirements	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.2	Stop Time	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.3	Failure Flash	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.4	Preemption	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.5	Priority	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.6	Fixed Time	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.7	Traffic Dependent Mode	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.8	Standby Mode	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.9	Failure Mode	Partial	CIMMS checks to see if these bits are populated but cannot verify if they are correct compared to the TSC.
3.3.3.3.2.14	No SPaT Available	Yes	Can be identified by observing missing SPaT message forward.
3.3.3.3.3.1	Current Movement State for a Signal Group	Yes	N/a
3.3.3.3.3.2	Unknown Current Movement State for a Signal Group	Yes	N/a

Functional Requirement ID	Functional Requirement	CIMMS Support	Notes
3.3.3.3.3.3	Flashing Yellow Arrow Permissive Movement	Partial	CIMMS will check if lights conflict with one another but cannot verify if they match the traffic bulb.
3.3.3.3.3.4	Protected and Permissive Clearance	Partial	CIMMS will check if lights are in contact with one another but cannot verify if they match the traffic bulb.
3.3.3.3.3.5	Resolve Protected Versus Permissive Movement	No	CIMMS does not currently check this requirement but has the information to do so. This functionality could be added with additional development.
3.3.3.3.3.12	Movement State for Signal Groups Identified	Yes	N/a
3.3.3.3.5.1	Time Change Details	Yes	N/a
3.3.3.3.5.2	Unknown Time Change Detail	Yes	N/a
3.3.3.3.5.3	Minimum End Time	Yes	N/a
3.3.3.3.5.4	Maximum End Time	Yes	N/a
3.3.3.3.5.5	Unknown Maximum End Time	Yes	N/a
3.3.3.3.5.7	Next Movement State Start Time	Yes	N/a

The CTW design to support SPaT message CTW performance measurement and evaluation as defined in the PMP is as follows:

- The data acquisition and analysis tools developed as part of the USDOT-funded Utah SMART Grant project between August 2023 and July 2025 will be the primary tool for ongoing performance assessments of SPaT messages that are generated and broadcast. This tool was created in conjunction with the Utah SMART Grant project team that included SCMS Manager specifically to assess CI messages (both SPaT and MAP) against CTI 4501 requirements for the purpose of validating intersections that fully meet the CTI 4501 requirements. UDOT will implement two to three mobile data acquisition tools that will be moved to different intersections to test the SPaT messages broadcast against CTI 4501 accuracy requirements. Approximately 5% of the CTW Program-deployed CIs will be tested with this approach. The data captured will be processed using the CAMP-developed SPaT assessment tool that is hosted by SCMS Manager.
 - The SPaT message validation tool will verify that the SPaT message follows the SAE J2735 format and is complete.
 - The SPaT message validation tool will compare values in the SPaT message to actual values in the data at the signal controller to validate the accuracy of values and periodicity of message creation and delivery.

- There are known exceptions to the CTI 4501 requirements that cannot be met today by the signal controllers in operation in Utah. These have been communicated to the CTI 4501 committee, and an approach is being developed to exclude these from the validation process that SCMS Manager will follow in the foreseeable future. These exceptions are noted in Table 5.
- The CV PFS Test Plan describing manual field collection at CIs will be implemented at limited intersections. The manual field collection and analysis of data conducted in the CV PFS project will be conducted on additional Utah intersections during the PEMP analysis to assess if SPaT message accuracy is acceptable. Approximately 5% of the CTW Program-deployed CIs will be tested with this approach.
- The CIMMS installation used in system testing will remain operational. The CIMMS installation will continue to operate during the PEMP assessment period of Phase 2 to detect times when SPaT messages are not generated or do not meet CTI 4501 message parameters.

Table 5. Exceptions to CTW Field Equipment CTI 4501 Conformance Design*Source: Athey Creek Consultants, April 2025*

Exception to CTI 4501 Requirements	Reason/Justification
1. 100% compliance of start time of Yellow Phase during preemption	The signal controller TSCBM output describing Start of Yellow Phase is not always accurate when the signal controller is operating during preemption. Without the ability to change signal controller operations or a fix from the controller manufacturer, the SCM cannot accurately generate these values 100% of the time.
2. 100% compliance of duration of Yellow Phase	The signal controller TSCBM output describing Duration of Yellow Phase is not always accurate. Analysis of data has shown that the first value output from the signal controller describing the time mark when the Yellow Phase will end is accurate, but later values are not accurate. Without the ability to change signal controller operations or a fix from the controller manufacturer, the SCM cannot accurately generate these values 100% of the time.
3. 100% compliance of periodicity of broadcasts	There are rare times when periodicity requirements are not met. The CTI 4501 requirements do not include a value for precision, resulting in a requirement for 100% adherence. Testing of the CTW CIs will be measured against conformance at the 90th percentile over one hour. The CTI 4501 Testing and Validation Task Force has agreed to this.

4. Requirements Traceability Matrix

The CTW SyRS outlines system requirements specific to the systems that are anticipated to be deployed as part of the CTW Program. However, many of those requirements apply to the expansion of existing V2X legacy systems with the original functionalities and specifications previously defined, given that the CTW Program will not include building a new system from the ground up. The system requirements presented in Table 6 apply only to new capabilities that are being developed as part of the CTW Program and described in Section 3, specifically: TIM interoperability, event message interoperability, and CI conformance to CTI 4501. Requirements describing expansion of existing functionalities and capabilities are not included.

Table 6 is organized to include the following information in each column:

- User Need: Provides traceability for each child requirement back to the user need identified in the CTW Con Ops document.
- Requirement ID: Provides a unique identifier for each requirement. The unique identifier is notated XX-YY-ZZ, where the initial “XX” digits reference the system of interest (SOI) (i.e., Central System = CS, FE = Field Equipment, VS = Vehicle Systems, or G = General), the middle “YY” digits are the parent requirement number, and the final “ZZ” digits are child requirements of the parent requirement.
- Type of Requirement: Parent requirements are the main requirements, with child requirements being more detailed subsets of the parent requirements.
-
- Requirement: Provides the system requirement specification, as identified in the CTW SyRS document.
- Design Components Internal to this CTW SDD: Provides references, when available, to sections of this SDD that relate to the given requirement.
- External Designs or Systems: Provides references to other design documents developed separately from the CTW Program that relates to the given requirement. For systems engineering and/or design decisions documented by material for one CTW state, the applicable state is identified (i.e., Utah, Colorado, and Wyoming).
- CTW Program Component: Describes the CTW state(s) (i.e., Utah, Colorado, and Wyoming) and system component (i.e., Central System, Field Equipment, or Vehicle Systems) to which the requirement applies.
- STP Reference: Provides the number of the STP, described in the CTW Operational Readiness Plan, in which the requirement is being tested.

- **Demonstration Supported by Requirement:** Provides the number of the demonstration(s), described in the CTW Operational Readiness Plan, for which the functionality provided through the requirement is necessary for the demonstration to be successful. This means the demonstration may not directly show the requirement; however the successful outcome of the demonstration may require the foundational capability enabled by the requirement or may be related to the requirement.

Table 6. Traceability of CTW Requirements for New Capabilities to the System Design
Source: Athey Creek Consultants, June 2025

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-13	CS-1	Parent	Create event reports. Central Systems shall create event reports.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-1.1	Child	<i>Event report content.</i> Central Systems shall create event reports that describe current roadway conditions or activities on the road that are expected to impact drivers. Final decisions on thresholds will be at each state's discretion.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-1.2	Child	<i>Event report sources.</i> Central Systems in each CTW state shall acquire data or other content from local sources to generate event reports.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-1.3	Child	<i>Event report timing.</i> Central Systems shall acquire and process local data and content to create or update event reports at a frequency that is determined by each state and may vary based on the type of event.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-1.4	Child	<i>Event report structure.</i> Central Systems shall create event reports that follow the CTW-agreed structure developed during the design process.	Section 3.2.2: Central System Event Message Interoperability Design	ngTMDD Specification	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-2	Parent	Interstate event exchange. Central Systems shall send event reports to the SDX.	Section 3.2.1: Central System Event Message Creation and Exchange Design	SDX	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-2.1	Child	<i>Timing of interstate event exchange.</i> Central Systems shall initiate the process to send event reports to the SDX within 1 minute of the event report being created.	- Section 3.2.1: Central System Event Message Creation and Exchange Design - Appendix: SDX ICD	SDX	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-13	CS-2.2	Child	<i>Confirmation of interstate event exchange.</i> Central Systems shall continue the process of attempting to send event reports to the SDX until the event exchange is confirmed.	- Section 3.2.1: Central System Event Message Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-9	CS-3	Parent	Update events. Central Systems shall update event reports as data or content from the sources are updated.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-9	CS-3.1	Child	<i>Share updates of events.</i> Central Systems shall send event report updates to the SDX within 1 minute after the event is updated following the same process as the initial send.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-9	CS-3.2	Child	<i>Share expiration of events.</i> Central Systems shall send event report expirations of events with the SDX within 1 minute after the event is determined to be expired.	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	n/a
CTW-8	CS-4	Parent	<i>Send TIMs to SDX.</i> Central Systems shall send all TIMs generated to the SDX as fully formed ASN.1 Unaligned Packed Encoding Rules (UPER)-encoded TIMs.	- Section 3.1.1: Central System TIM Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-2	Demo 6
CTW-8	CS-4.1	Child	<i>Timing of TIM exchanges.</i> Central Systems shall send TIMs to the SDX within 1 minute after the fully-formed, ASN.1 UPER-encoded TIM is generated.	- Section 3.1.1: Central System TIM Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-2	n/a
CTW-8	CS-4.2	Child	<i>Confirmation of TIM exchanges.</i> Central Systems shall continue the process of sending TIMs to the SDX until the TIM exchange is confirmed.	- Section 3.1.1: Central System TIM Creation and Exchange Design; - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-2	n/a
CTW-8	CS-5	Parent	<i>Update TIMs in SDX.</i> Central Systems shall send updated TIMs to the SDX within 1 minute after the TIM is updated, following the same process the initial TIM send.	- Section 3.1.1: Central System TIM Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-2	n/a
CTW-8	CS-6	Parent	<i>Expire TIMs in SDX.</i> Central Systems shall send TIM expirations to the SDX within 1 minute after the TIM expiration is determined by the Central System, following the same process as when sending the initial TIM.	- Section 3.1.1: Central System TIM Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-2	n/a
CTW-13	CS-7	Parent	<i>Compatible SAE J2735 versions.</i> When continuing message exchanges that are currently operational in each CTW state, the Central Systems shall exchange messages as defined in SAE J2735 standards.	n/a	Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis Wyoming: Wyoming CV Pilot Documentation Utah: Systems Engineering Document for CIs Utah: Systems Engineering Document for Connected Roadways	Utah, Colorado, and Wyoming Central Systems	STP-2	Demo 5
CTW-13	CS-7.1	Child	<i>Central Systems receive J2735 messages.</i> Central Systems shall be capable of receiving and processing messages as defined in J2735 standards in all of the following versions: 2016, 2020, and 2024.	n/a	Utah: Systems Engineering Document for CIs Utah: Systems Engineering Document for Connected Roadways	Utah, Colorado, and Wyoming Central Systems	STP-2	Demo 1 Demo 3 Demo 5
CTW-13	CS-7.2	Child	<i>Central Systems send J2735 messages.</i> Central Systems shall generate all messages to be exchanged using C-V2X communications as defined by J2735 according to one of the following versions: 2016, 2020, or 2024.	- Section 3.4.2: Central System CTI 4501 Conformance Design - Section 3.4.3 Field Equipment CTI 4501 Conformance Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-2	Demo 5

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-4	CS-8	Parent	Expand ingest of spot weather impact warning (SWIW)-related data. Central Systems shall be capable of receiving, processing, and storing BSMs received from additional RSUs deployed in the CTW Program.	n/a	• Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis • Utah: Systems Engineering Document for CIs	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 1
CTW-5	CS-9	Parent	Expand locations supported by curve speed warning (CSW) messages. Central Systems shall increase creation of CSW messages to include messages for curves near expansion RSUs.	Section 3.2.1: Central System TIM Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 5
CTW-6	CS-10	Parent	Expand TIM creation. Central Systems shall expand the type and number of TIMs created.	• Section 3.2.1: Central System TIM Creation and Exchange Design • Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 5
CTW-6	CS-10.1	Child	<i>Expand TIM locations to include additional RSU locations. Central Systems shall create TIMs, when appropriate, that describe conditions downstream of the additional RSUs added in this project and identify the appropriate RSU for broadcast. Determination of what is appropriate is to be defined by each state and is expected to vary by TIM.</i>	Section 3.2.1: Central System TIM Creation and Exchange Design	n/a	Utah and Colorado Central Systems	STP-3	Demo 5
CTW-6	CS-10.2	Child	<i>Expand TIM locations to include all areas of the state. Central Systems shall create TIMs, when appropriate, that describe conditions anywhere in the state to be shared through the SDX. Determination of what is appropriate is to be defined by each state and is expected to vary by TIM.</i>	Section 3.1.1: Central System TIM Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 6
CTW-6	CS-10.3	Child	<i>Expand TIM locations to include other states. Central Systems shall consider TIMs and event reports received from adjacent states and create TIMs, when appropriate, that communicate the information to travelers heading in the direction of the adjacent states' events. Determination of what is appropriate is to be defined by each state and is expected to vary by TIM.</i>	Section 3.1.1: Central System TIM Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 7
CTW-14	CS-11	Parent	Central Systems support storage of data for expansion sites and services. Central Systems shall provide capacity to store the additional data added by expansion systems.	n/a	• Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis • Utah: Systems Engineering Document for CIs	Utah and Colorado Central Systems	STP-4	All Demos

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-14	CS-11.1	Child	<i>Support storage for additional BSM data.</i> Central Systems shall provide capacity to store BSM messages collected by RSUs added by the CTW Program to meet the retention policies of each CTW state.	n/a	• Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis • Utah: Systems Engineering Document for CIs • Utah: Systems Engineering Document for Connected Roadways	Utah and Colorado Central Systems	STP-4	Demo 1 Demo 3 Demo 5
CTW-14	CS-11.2	Child	<i>Support storage for additional TIMs.</i> Central Systems shall provide capacity to store the additional TIMs created by the expanded functions in CTW, to meet the retention policies of each CTW state.	n/a	• Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis • Utah: Systems Engineering Document for Connected Roadways	Utah and Colorado Central Systems	STP-4	Demo 5 Demo 6 Demo 7
CTW-14	CS-11.3	Child	<i>Support storage for additional SRMs and Signal Status Messages (SSMs).</i> Central Systems shall provide capacity to store the additional SRMs and SSMs created and exchanged for the expanded CIs supporting CIPT, to meet the retention policies of each CTW state.	n/a	Utah: Systems Engineering Document for CIs	Utah and Colorado Central Systems	STP-4	Demo 1
CTW-14	CS-11.4	Child	<i>Support storage for additional CI data.</i> Central Systems shall provide capacity to store the additional SPaT, MAP, and RTCM messages and associated data created and exchanged for the expanded CIs, to meet the retention policies of the CTW state adding CIs.	n/a	Utah: Systems Engineering Document for CIs	Utah Central System	STP-4	Demo 1 Demo 2
CTW-14	CS-11.5	Child	<i>Support storage for Sensor Data Sharing Messages (SDSMs).</i> Central Systems shall provide capacity to store the SDSM messages created and exchanged in support of the VRU Safety Systems added in Utah to meet the retention policies of the state of Utah.	n/a	• Utah: Systems Engineering Document for CIs • Utah: Systems Engineering Document for VRU Safety	Utah Central System	STP-4	Demo 3
CTW-15	CS-12	Parent	Central Systems monitor expansion sites. Central Systems shall monitor health of additional Field Equipment deployed in each state, as documented in the ConOps sections 3.2.1.2, 3.2.2.2, 3.3.1.2, and 3.4.1.2.	n/a	• Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis • Utah: Systems Engineering Document for CIs • Utah: Systems Engineering Document for Connected Roadways	Utah and Colorado Central Systems	STP-5	Demo 1 Demo 3 Demo 4 Demo 5 Demo 7

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-18	CS-13	Parent	<i>TIMs adherence to documented best practices. Central Systems shall generate the content and structure of TIMs in a way that adheres to CTW Program-agreed TIM guidance and best practices documented in the design process.</i>	- Section 3.1.2: Central System TIM Interoperability Design - Traveler Information Message (TIM) Documentation Version 1.0: Use of the Traveler Information Structure to Build Standard Traveler Information Messages	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 5 Demo 6 Demo 7
CTW-8	CS-14	Parent	<i>SDX Functionality. Existing SDX functions should be able to exchange the additional number of TIMs generated from expanded CTW locations.</i>	n/a	SDX	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 5
CTW-6	CS-15	Parent	<i>Acquire events from other CTW states. Central Systems shall acquire event reports from the SDX.</i>	- Section 3.2.1: Central System Event Message Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	Demo 7
CTW-6	CS-15.1	Child	<i>Frequency of acquiring Event Reports from SDX. Central Systems shall acquire event reports from the SDX at a frequency defined locally by each CTW state.</i>	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	Demo 7
CTW-6	CS-15.2	Child	<i>Parameters of Event Report Queries from SDX. Central Systems shall query the SDX for event reports within a geographic boundary set by the Central System and defined locally by each CTW state.</i>	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-1	Demo 7
CTW-6	CS-16	Parent	<i>Create TIMs based on other states' event reports. Central Systems should create TIMs based on the event reports received from other CTW states, when appropriate.</i>	Section 3.2.1: Central System Event Message Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 7
CTW-6	CS-17	Parent	<i>Acquire TIMs from other CTW states. Central Systems may acquire TIMs from the SDX.</i>	Section 3.1.1: Central System TIM Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 7
CTW-6	CS-17.1	Child	<i>Location based query of SDX TIMs. Central Systems may query the SDX for active TIMs within a geographic boundary set by the Central System and defined locally by each CTW state.</i>	- Section 3.1.1: Central System TIM Creation and Exchange Design - Appendix: SDX ICD	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 7
CTW-6	CS-17.2	Child	<i>Acquire TIMs from other CTW states. Central Systems may acquire TIMs from the SDX at a frequency determined by each site.</i>	Section 3.1.1: Central System TIM Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 7
CTW-6	CS-18	Parent	<i>Distribute TIMs received from other states. Central Systems may distribute TIMs that were acquired from the SDX to RSUs for broadcast if the TIM valid region is within a defined distance (to be defined individually by each state) downstream of the RSU location.</i>	Section 3.1.1: Central System TIM Creation and Exchange Design	n/a	Utah, Colorado, and Wyoming Central Systems	STP-3	Demo 7

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-13	FE-1	Parent	Field Equipment-compatible SAE J2735 versions. All CTW Field Equipment added through this effort shall send and receive messages as defined in SAE J2735 standards.	n/a	• Utah: Systems Engineering Document for Connected Intersections • Utah: Systems Engineering Document for Connected Roadways	Utah and Colorado Field Equipment	STP-6, STP-8	Demo 1 Demo 2 Demo 3 Demo 5 Demo 7
CTW-13	FE-1.1	Child	<i>Field Equipment receive messages in compatible SAE J2735 versions.</i> All CTW Field Equipment added through this effort shall be capable of receiving and processing messages as defined in J2735 standards in all of the following versions: 2016, 2020, and 2024.	• Section 3.1.3: Field Equipment TIM Interoperability Design	n/a	Utah and Colorado Field Equipment	STP-6, STP-8	Demo 1 Demo 2 Demo 3 Demo 5 Demo 7
CTW-13	FE-1.2	Child	<i>Field Equipment send messages in compatible SAE J2735 versions.</i> CTW Field Equipment added through this effort that generate messages shall generate and send messages as defined in SAE J2735 according to one of the following versions: 2016, 2020, 2024.	• Section 3.1.3: Field Equipment TIM Interoperability Design	n/a	Utah and Colorado Field Equipment	STP-6	Demo 1 Demo 2 Demo 3 Demo 5 Demo 7
CTW-1	FE-2	Parent	Expansion sites adhere to earlier qualifications. Expansion sites for CIPT shall be identified that meet location qualifications defined in earlier deployments.	n/a	CTW Comprehensive Installation Plan (CIP) (Section 7.1.1; Table 7-1)	Utah Field Equipment	STP-7	Demo 1
CTW-1	FE-2.1	Child	<i>Expansion sites support transit use.</i> Expansion sites for CIPT shall include intersections along core transit routes that would benefit from improved schedule adherence.	n/a	CTW CIP (Section 7.1.1; Table 7-1)	Utah Field Equipment	STP-7	Demo 1
CTW-1	FE-2.2	Child	<i>Expansion sites support snowplow use.</i> Expansion sites for CIPT shall include intersections along UDOT snowplow routes and where snowplows are (or planned to be) equipped to send CIPT requests.	n/a	CTW CIP (Section 7.1.1; Table 7-1)	Utah Field Equipment	STP-7	n/a

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-1	FE-2.3	Child	<i>Expansion sites support emergency vehicle use.</i> Expansion sites for CIPT shall include intersections used by emergency vehicles that are (or planned to be) equipped to send CIPT requests.	n/a	CTW CIP (Section 7.1.1; Table 7-1)	Utah Field Equipment	STP-7	n/a
CTW-2	FE-3	Parent	<i>CI expansion sites to address needs.</i> CI expansion sites supporting CIPT shall be in locations where there is existing or planned vehicular traffic that will be equipped to submit priority requests.	n/a	CTW CIP (Section 7.1.1; Table 7-1)	Utah Field Equipment	STP-7	n/a
CTW-3	FE-4	Parent	<i>CI expansion sites shall continue adherence to CTI 4501.</i> CI expansion sites shall follow CTI 4501/1 to the extent possible considering legacy systems involved (e.g., TSCs) as of April 2025 and as determined in the design process.	- Section 3.4.2: Central System CTI 4501 Conformance Design - Section 3.4.3: Field Equipment CTI 4501 Conformance Design	Connected Transportation Interoperability (CTI) 4501 Connected Intersections (CI) Implementation Guide	Utah Field Equipment	STP-6	Demo 2
CTW-7	FE-5	Parent	<i>Connected Roadway expansion sites to address needs.</i> RSUs deployed at Connected Roadway expansion sites shall be in locations where there is current or planned vehicular traffic that will be equipped to receive messages.	n/a	Utah: CTW CIP (Section 7.1.2; Table 7-2) Colorado: CTW CIP (Section 7.1.3; Table 7-3)	Utah and Colorado Field Equipment	STP-7	n/a
CTW-7	FE-6	Parent	<i>Connected Roadway expansion sites interoperable with legacy Central Systems.</i> RSUs deployed at Connected Roadway expansion sites shall be interoperable with legacy Central Systems deployed in Utah and Colorado as described in the CTW ConOps Sections 3.2.2 (Utah) and 3.4.2 (Colorado).	n/a	Colorado: V2X Technology, Safety, and Mobility Improvement, CDOT V2X BUILD Grant, Systems Engineering Analysis Utah: Systems Engineering Document for Connected Roadways	Utah and Colorado Field Equipment	STP-6	Demo 5
CTW-10	FE-7	Parent	<i>Connected Roadway expansion sites to address needs.</i> Connected Roadway expansion sites that receive BSMs broadcast by passing vehicles shall be in locations where existing or planned equipped vehicles travel.	n/a	Utah: CTW CIP (Section 7.1.2; Table 7-2) Colorado: CTW CIP (Section 7.1.3; Table 7-3)	Utah and Colorado Field Equipment	STP-7	n/a

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-11	FE-8	Parent	SCMS credentialing interoperability Connected Roadway expansions. SCMS credentialing on Connected Roadway and CI expansion sites shall be interoperable with credentialing performed for existing CTW systems, as defined in the CTW ConOps Sections 3.2 and 3.4.	Section 3.3.1: SCMS Certificate Interoperability with Other States	n/a	Utah and Colorado Field Equipment	STP-6	Demo 7
CTW-12	FE-9	Parent	VRU safety system expansion sites adhere to earlier qualifications. Expansion sites for VRU safety systems shall be identified that meet location qualifications defined in existing deployments.	n/a	• CTW CIP (Section 7.2; Table 7-4) • Systems Engineering Document for VRU Safety at CIs	Utah Field Equipment	ORP Section 2.3.4 Other Inspections	n/a
CTW-12	FE-9.1	Child	<i>VRU safety system expansion sites at sites with consistent pedestrian traffic.</i> Expansion sites for VRU safety systems shall be identified that have pedestrian crash rates that are above the average number of pedestrian crashes per intersection over a 10-year period (currently 3.2 crashes/year) at SIs.	n/a	CTW CIP (Section 7.2; Table 7-4)	Utah Field Equipment	ORP Section 2.3.4 Other Inspections	n/a
CTW-12	FE-10	Parent	SDSM messages interoperable to legacy systems. SDSM messages broadcast by VRU safety systems in expansion sites shall be as defined in SAE J3224.	n/a	SAE J3224	Utah Field Equipment	STP-6	Demo 3
CTW-16	FE-11	Parent	Process SCMS certificates from external agency fleet vehicles. RSUs in CTW states shall have the capability to validate SCMS certificates that accompany messages broadcast by fleet vehicles owned by other CTW sites.	Section 3.3.1: SCMS Certificate Interoperability with Other States	n/a	Utah, Colorado, and Wyoming Field Equipment	STP-6	Demo 7
CTW-17	FE-12	Parent	Enable fleet vehicles to receive SCMS top offs without cellular connection. Selected sites shall include the capability to enable C-V2X-equipped fleet vehicles without cellular connectivity to connect to the Internet through Wi-Fi to enable the fleet vehicles to download SCMS top offs from the contracted SCMS provider.	n/a	Utah: Systems Engineering Document for CIs	Utah and Colorado Field Equipment	STP-8	n/a
CTW-13	VS-1	Parent	Vehicle Systems-compatible SAE J2735 versions. All CTW Vehicle Systems added through this effort shall send and receive messages as defined in SAE J2735 standards.	n/a	Utah: Systems Engineering Document for CIs	Utah Vehicle Systems (Transit Vehicles, Snowplows, GM Vehicle)	STP-9	Demo 1

User Need	Requirement ID	Type of Requirement	Requirement	Design Components Internal to this CTW SDD	External Designs or Systems	CTW Program Component	STP Reference	Demonstration Supported by Requirement
CTW-13	VS-1.1	Child	<i>Vehicle Systems receive in compatible SAE J2735 versions.</i> All CTW Vehicle Systems added through this effort shall be capable of receiving and processing messages as defined in J2735 standards in all of the following versions: 2016, 2020, and 2024.	n/a	Utah: Systems Engineering Document for CIs	Utah Vehicle Systems (Transit Vehicles, Snowplows)	STP-9	Demo 1
CTW-13	VS-1.2	Child	<i>Vehicle Systems send in compatible SAE J2735 versions.</i> All CTW Vehicle Systems added through this effort shall generate and send messages as defined in SAE J2735 according to one of the following versions: 2016, 2020, or 2024	n/a	Utah: Systems Engineering Document for CIs	Utah Vehicle Systems (Transit Vehicles, Snowplows)	STP-9	Demo 1
CTW-1	VS-2	Parent	SRM messages interoperable to legacy systems. SRM messages broadcast by Vehicle Systems deployed in the CTW project that are CIPT-participating vehicles shall be interoperable with legacy CIPT Field Equipment.	n/a	Utah: Systems Engineering Document for CIs	Utah Vehicle Systems (Transit Vehicles, Snowplows)	STP-9	Demo 1
CTW-16	VS-3	Parent	Process SCMS certificates from external agency RSUs. Vehicle Systems operated by CTW members shall have the capability to validate SCMS certificates that accompany messages broadcast from RSUs operated by other CTW sites.	Section 3.3.1: SCMS Certificate Interoperability with Other States	n/a	Utah Vehicle Systems (GM Vehicle)	STP-9	Demo 7
CTW-17	VS-4	Parent	Receive Wi-Fi top offs of SCMS certificates. Vehicle Systems without cellular communications shall include the capability to establish internet connection through Wi-Fi to receive top offs of SCMS certificates directly from contracted SCMS providers.	n/a	Utah: Systems Engineering Document for CIs	Utah Vehicle Systems (Transit Vehicles, Snowplows)	STP-8	n/a

Appendix. Connecting the West – Situation Data Exchange (SDX) Interface Control Document (ICD)

Scope-limited to interfaces between the Utah, Wyoming, and Colorado central systems (state Traffic Management Center [TMC]/Intelligent Transportation Systems [ITS] backends) and the CTW SDX, specifically for TIMs and event reports exchanged via Hypertext Transfer Protocol (Secure) (HTTP[S])/REpresentational State Transfer (REST) and Kafka.

Document Control

- **Owner:** CTW Architecture and Standards Team (Trihydro)
- **Contributors:** UDOT, WYDOT, CDOT, Partner Vendors
- **Version:** v0.1 (Draft)
- **Status:** In Development
- Change Log:
 - v0.1 – Initial scaffold aligned to WYDOT CV Pilot ICD format; adds SDX Kafka event interfaces; limits scope to TIMs and event reports

References

- Connected Vehicle Pilot Deployment Program Phase 2 – Interface Control Document (ICD) – WYDOT CV Pilot, FHWA-JPO-17-468, Final Report June 1, 2018.
- [SDX API Specification \(Swagger/OpenAPI\)](#) — (current beta instance; use exported OpenAPI JavaScript Object Notation [JSON] for normative field names and enums).
- [ngTMDD standard](#).
- SAE J2735 — TIM (latest adopted revision used by the CTW Program).
- American Association of State Highway and Transportation Officials (AASHTO)/ITE ngTMDD v3.03c — for legacy event/condition references where applicable.

Acronyms and Definitions

- **CTW** – Connecting the West
- **SDX** – Situation Data Exchange
- **TIM** – Traveler Information Message (SAE J2735)
- **TMC** – Traffic Management Center
- **BSM** – Basic Safety Message (contextual)
- **SCMS** – Security Credential Management System (signed messages context)
- **Kafka** – Apache Kafka event streaming platform
- **Topic** – Kafka logical feed/channel
- **ngTMDD** – Next-Generation Traffic Management Data Dictionary
- **Key** – Kafka record key used for partitioning/ordering
- **Schema Registry** – Registry for Avro/JSON schemas and compatibility

System Overview

Physical System Overview

The physical view in Figure A-1 represents the block diagram of the systems and interfaces, which are numbered for reference for discussion. This provides a detailed graphical view of the physical architecture of the CTW system and interactions that occur within and between the different entities through the SDX system. Please note that this diagram is limited to the data-sharing aspects of the CTW system.

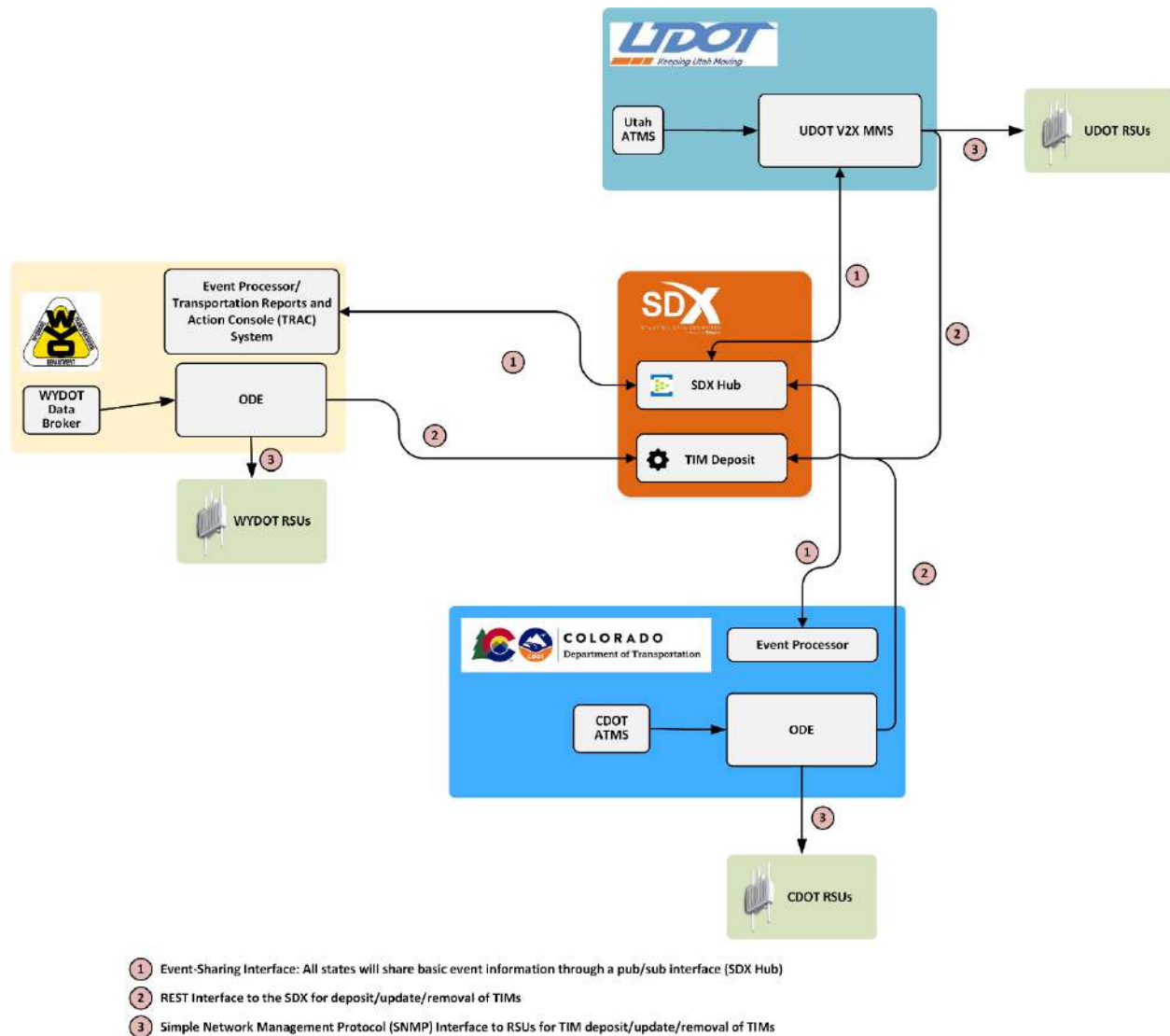


Figure A-1. Physical View of the CTW System

Source: Trihydro, 2025

State central systems (UDOT, WYDOT, and CDOT) publish and/or consume TIMs and event reports with the SDX. Exchanges occur via:

- **REST (HTTPS)** for control/management and pull/push of TIM payloads (where applicable per SDX Application Programming Interface [API]).
- **Kafka** for streaming event reports and optionally TIM distribution, with SDX as the broker/namespace provider.

Interface Scope

- **In Scope:**
 - State Central System to and from SDX: TIMs via REST only (publish, query/revoke) and event reports via Kafka (publish/subscribe)
 - Transport protocols: HTTPS (REST) for TIMs; Kafka (Transport Layer Security [TLS]/mutual Transport Layer Security [mTLS]) for event reports
- **Out of Scope (for this ICD):** RSU/OBU, SCMS signing workflows, third-party aggregators not routed the through SDX

List of Interfaces

This section lists the interfaces that are being defined in the Security and Access Control section of this appendix.

Heading descriptions for Table A-1 are as follows:

- CTW Interface Number: The interface number from Physical View, Figure A-1
- Source Element: The system that provides data for the flow
- Destination Element: The system that consumes the data for the flow
- Communication Profile: Communication protocol(s) used
- Application Information Standard: Key standard(s) governing this information exchange

Table A-1. List of Data, Information Exchanges, and Systems Engineering Tool for Intelligent Transportation (SET-IT) Communication Profile Template for Each Interface in WYDOT CV Pilot
Source: Trihydro, 2025

CTW Interface Number	Source Element	Destination Element	Communication Profile	Application Information Standard
1	Central System	SDX	REST, Kafka	ngTMDD Event Report, JSON
2	Central System	SDX	REST	J2735, TIM Content, ngTMDD

Data Sharing Roles and Flows

Roles

- **Publisher:** System producing a TIM or event report to SDX.
- **Consumer:** System subscribing to/retrieving TIMs or event reports from SDX.
- **Broker/Exchange:** SDX manages topics, authZ, and distribution.

High-Level Flows

TIM Publish (State to SDX): State System Posts a TIM Package to SDX Via REST

This subsection describes the process where a state system posts a TIM package to the SDX as described in interface 2 of Figure A-1 above. All TIMs generated from the Central Systems will be deposited to the SDX system.

External References

- Traveler Information Message: SAE J2735, SAE J2540-2
- REST interface standards

Covered Information Flows

Table A-2 indicates the information flow of TIMs to the ODE from the Central System.

Table A-2. Flow: Central System sends TIMs to ODE

Source: Trihydro, 2025

Flow Name	Figure Number	Source Element	Destination Element	Interface Number
I2V Situation Awareness TIM (C2C and C2I)	4-13	Central System	SDX	2

Dialogs

Dialog: Central System sends TIMs to SDX

State Central Systems deposit TIMs to the SDX via HTTP(s) REST in the Unified Modeling Language (UML) shown in Figure A-2. SDX uses authorization API tokens to authenticate users of their web applications.

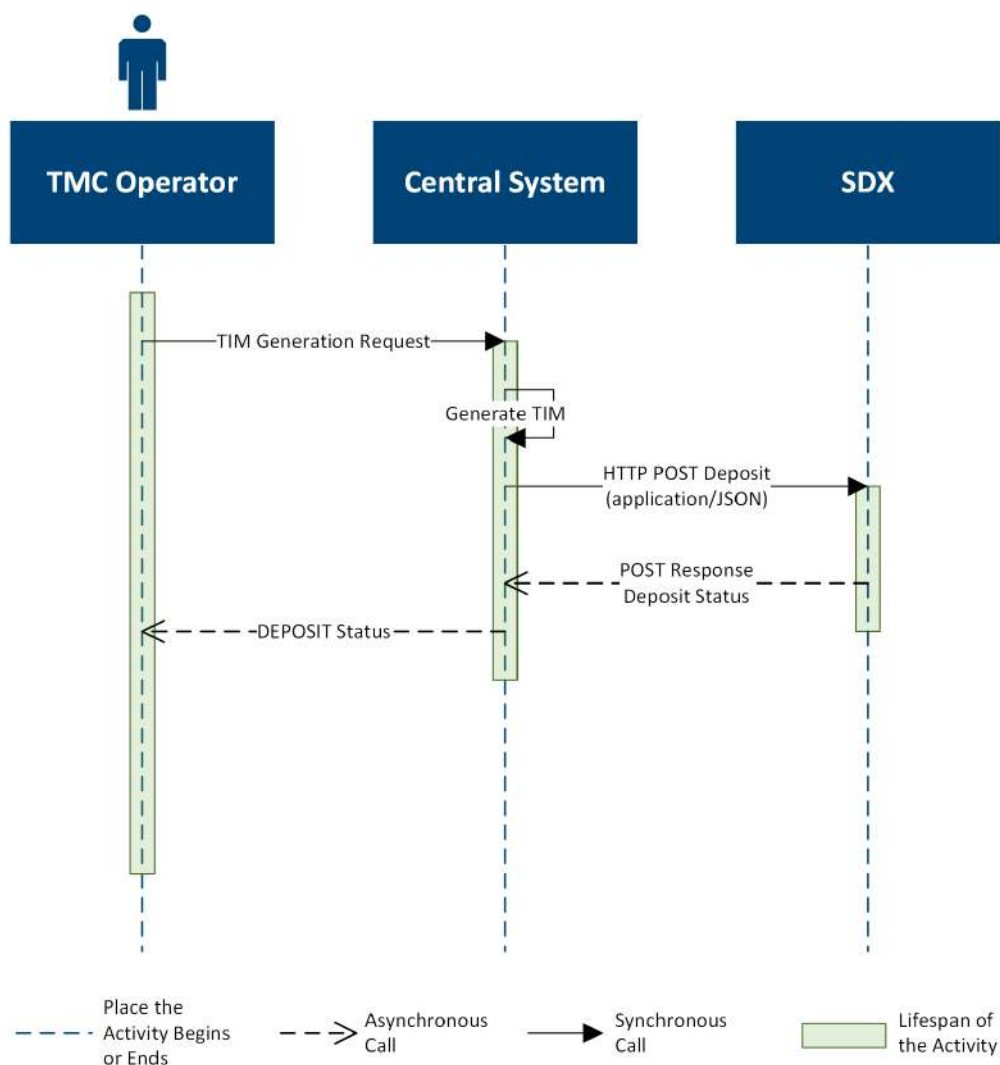


Figure A-2. Sequence Diagram: Central System Sends TIMs to SDX

Source: Source: Trihydro, 2025

Messages

- TIM: Described in SAE J2735.

TIM Distribution (SDX to States): SDX Exposes TIMs for Pull (REST) to Authorized Consumers.

This subsection describes the process where a state system retrieves a TIM package from the SDX as described in interface 2 of Figure A-1 above. State Central Systems will retrieve relevant TIMs from the SDX in order to analyze or potentially rebroadcast these TIMs.

External References

- TIM: SAE J2735, SAE J2540-2

- REST interface standards.

Covered Information Flows

Table A-3 indicates the information flow of TIMs to the ODE from the Central System.

Table A-3. Flow: Central System Sends TIMs to ODE
Source: Trihydro, 2025

Flow Name	Figure Number	Source Element	Destination Element	Interface Number
I2V Situation Awareness TIM (C2C and C2I)	4-13	SDX	Central System	2

Dialogs

Dialog: Central System Retrieves TIMs from SDX

State Central Systems retrieve TIMs from the SDX via HTTP(s) REST in the UML shown in Figure A-3. SDX uses authorization API tokens to authenticate users of their web applications.

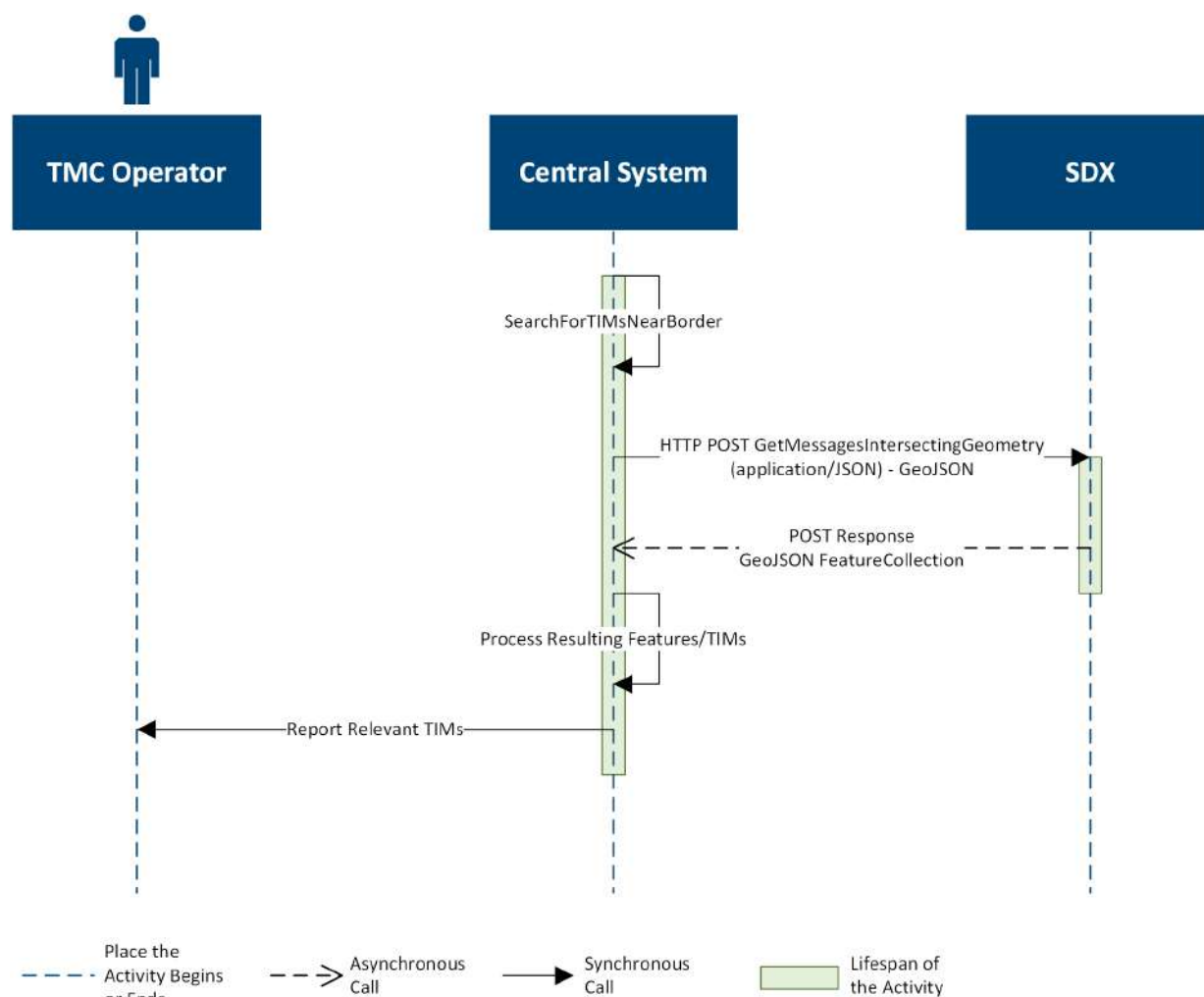


Figure A-3. Sequence Diagram: Central System Retrieves TIMs from SDX

Source: Trihydro, 2025

Messages

- TIM: described in SAE J2735.

Event Report Publish (State to SDX): State System Publishes Event Reports to Kafka Topic(s) Managed by SDX

This subsection describes the process where a state system posts an event report package to the SDX as described in interface 1 of Figure A-1 above. All events generated from the Central Systems will be deposited to the SDX system.

External References

- Event Report: ngTMDD EvenInformationResponse format as described in the ITE [Next Generation Traffic Management Data Dictionary](#), specifically ngTMDD Volume I - ConOps and Requirements and ngTMDD Volume II- Design Document.
- Kafka interface standards.

Covered Information Flows

Table A-4 indicates information flows of event reports from the Central System to the ODE.

Table A-4. Flow: Central System Sends Event Reports to ODE

Source: Trihydro, 2025

Flow Name	Figure Number	Source Element	Destination Element	Interface Number
Event Report Deposit (C2C)	4-13	Central System	SDX	1

Dialogs

Dialog: Central System Sends TIMs to SDX

State Central Systems deposit event reports to the SDX via Kafka in the UML shown in Figure A-4. SDX uses Simple Authentication and Security Layer (SASL) to authenticate users of their web applications.

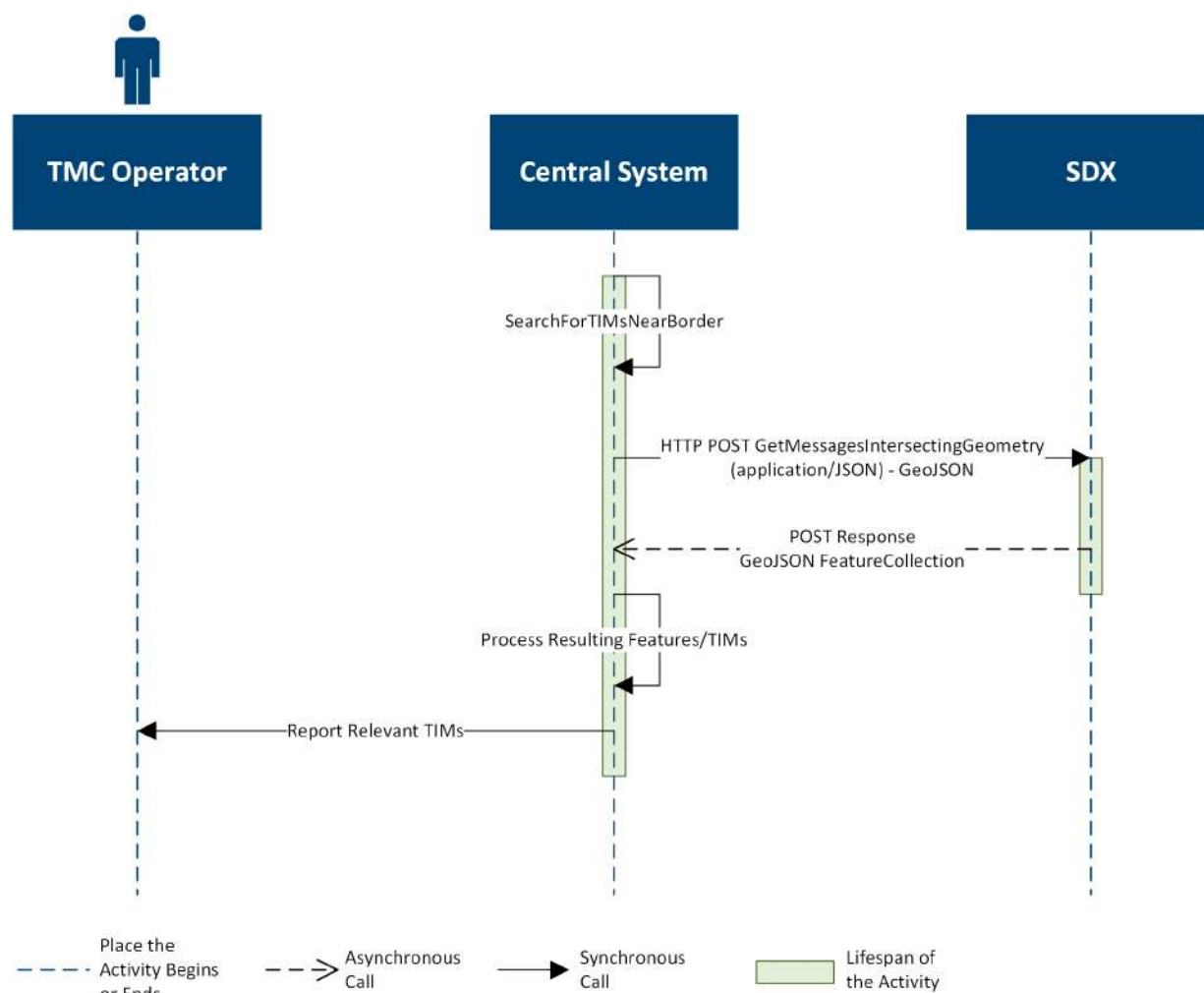


Figure A-4. Sequence Diagram: Central System Sends Event Reports to SDX

Source: Trihydro, 2025

Messages

Event report messages are generated using the ngTMDD: described in the SDX REST for TIMs section of this appendix.

Event Report Subscribe (SDX to States): State Consumers Subscribe to SDX Kafka Topics to Receive Cross-state Event Reports

This subsection describes the process where a state system retrieves event reports from the SDX as described in interface 1 of Figure A-1 above.

External References

- Event Report: ngTMDD EvenInformationResponse format as described in [Volume I and Volume II](#).
- REST interface standards.

Covered Information Flows

Table A-5 indicates information flows of ngTMDD format reports from the SDX to the Central Systems.

Table A-5. Flow: Central System Sends Event Reports to Central Systems

Source: Trihydro, 2025

Flow Name	Figure Number	Source Element	Destination Element	Interface Number
Event Report Retrieval (C2C)	4-13	SDX	Central System	1

Dialogs

Dialog: Central System Sends TIMs to SDX

State Central Systems deposit event reports to the SDX via Kafka in the UML in Figure A-5. SDX uses REST API Tokens to authenticate users of their web applications.

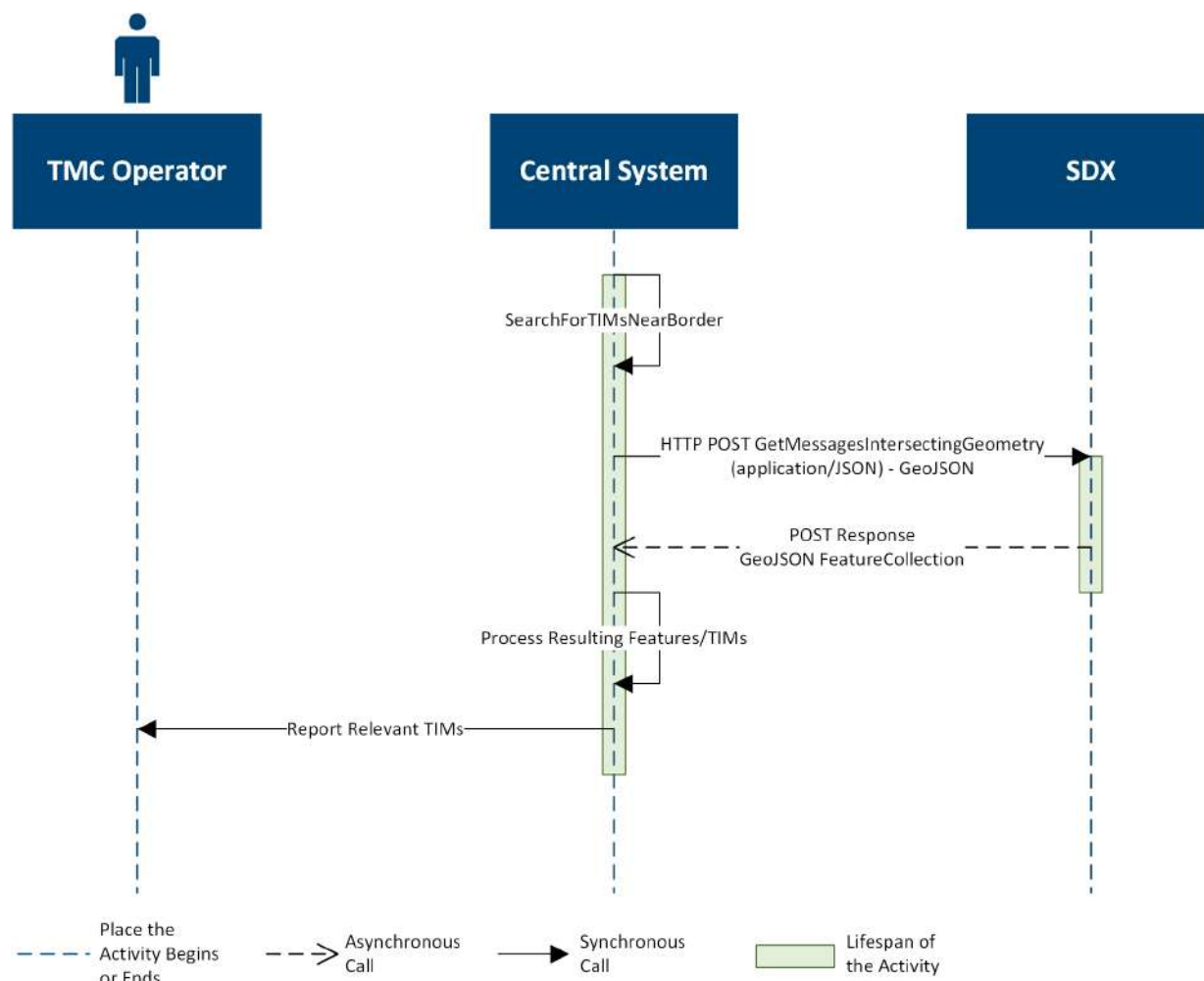


Figure A-5. Sequence Diagram: Central System Retrieves Event Reports from the SDX
 Source: Trihydro, 2025

Messages

The messages will use the ngTMDD EvenInformationResponse format as described in [Volume I and Volume II dated 3/23/2026](#).

Security and Access Control

- **Transport Security:** TLS 1.2+ for REST and Kafka; mTLS preferred for Kafka brokers.
- **AuthN:**
 - REST: OAuth2 client credentials or mTLS client certs (per SDX configuration).
 - Kafka: SASL_SSL (OAuthBearer).
- **AuthZ:** Topic- and endpoint-level ACLs, least-privilege.

- **Certificates and Keys:** Issuance, rotation, and renewal procedures (Public Key Infrastructure [PKI] authority, lifetimes, rollover window).
- **SCMS Interaction (Contextual):** If TIMs are ingested/signed for on-road distribution, reference SCMS integration documents (outside scope for transport security; mention only for integrity context).

Message Semantics and Schemas

TIM Packages

- **Canonical Representation:** SAE J2735 TIM payloads (UPER/ASN.1) encapsulated in JSON schema per SDX API contract.
- **Exchange Format(s):**
 - **REST only:** JSON envelope with TIM as base64 UPER or JSON-transcoded fields (as defined in SDX Swagger) – see the SDX REST for TIMs section of this appendix.

Event Reports

Event reports will be shared using the ngTMDD EventInformationResponse data object defined in [Volume II of the ngTMDD spec](#):

- **Exchange Format(s):** REST or Kafka (JSON or Avro with Schema Registry) and backward-compatible evolution.
- **Identifiers and Idempotency:** EventInformationResponse.EventReference.EventId (EventId) shall be used as the Kafka message key and idempotency key.

Interface Specifications

End-to-End Requirements

- **Reliability:** At-least-once delivery for Kafka; idempotent processing using eventId / timId.
- **Ordering:** Partition by (jurisdiction, corridorId) or (eventId) to preserve per-entity order.
- **Throughput Targets:** Define msgs/sec per topic; peak storm/event conditions.
- **Latency Targets:** Ingest-to-available ≤ 5 seconds (95th percentile).
- **Retention:** Kafka topic retention 2 days; TIM archival 30 days; compaction for latest-by-key where applicable.
- **Compatibility:** Backward-compatible schema evolution (Schema Registry backward mode).

SDX REST for TIMs

Source of Truth: SDX OpenAPI v1 (link to export provided). This section captures the normative operations, request/response models, and error behaviors for TIM lifecycle.

External References

- TIM: SAE J2735, SAE J2540-2
- REST interface standards are described in the Message Semantics and Schemas section of this appendix.

Deposit TIM(s)

- **POST** /api/deposit — *Deposits an advisory message (TIM) into the SDX*
operationId: Deposit
Request Body (application/json): DepositRequest
Model: (See Table A-6, below)
- **POST** /api/deposit-multi — *Deposits multiple TIMs*
operationId: DepositMulti
Request Body: DepositRequestList { depositRequests: DepositRequest[] }
Response: 200, DepositMultiSummary { depositedRecordIds[], failedDepositRequests[], failedAuthorizedAsds[] }; 400, 403, 500

Table A-6. Model for Depositing TIMs

Source: Trihydro, 2025

Field	Type	Required	Notes
encodedMsg	string	Yes	Encoded J2735 TravelerInformation; supports hex/base64/uper via encodeType
encodeType	enum(hex,base64,uper)	Yes	Encoding of encodedMsg
estimatedRemovalDate	date-time	No	Used as TIM expiration (maps to validTo)
sharedId	string	No	Optional correlation; if empty, orgId is derived from user
Responses: 200 (body: int32 recordId), 400, 403, 500	N/a	No	N/a

Query and Retrieve TIMs

- **GET** /api/deposited-by-me/{semiDialogId} — *Get non-expired messages deposited by caller*
operationId: DepositedByMe
Query param: optional semiDialogId (accepted values: 154,155,156,157,160,161,162,163)
Response: 200, AdvisorySituationDataDeposit[]; 400, 500
- **POST** /api/GetData — *List advisory messages*
operationId: GetData
Request Body: Query (filters: dialogID, paging, bbox via nwLat/nwLon/seLat/seLon, date ranges, orderBy)
Response: 200, AdvisorySituationDataDeposit[]; 400, 401, 500

- **POST** /api/GetDecodedMessages — *List decoded TravelerInformation frames (human-readable JSON)*
operationId: GetDecodedMessages
Request Body: Query
Response: 200, MessageFrame[]
- **GET/POST** /api/GetDataByRecordId — *Fetch a message by RecordID*
operationId: GetDataByRecordId
Request: query recordId **or** body RecordIdRequest { recordId, type: Hex|Int }
Response: 200, AdvisorySituationDataDeposit; 204 if none; 400, 500
- **POST** /api/GetBundles — *List Advisory Situation Bundles*
operationId: GetBundles
Request Body: Query
Response: 200, AdvisorySituationBundle[]
- **POST** /api/GetGeoJsonData — *FeatureCollection view (includes ITIS properties)*
operationId: GetGeoJsonData
Request Body: Query
Response: 200, FeatureCollection
- **GET** /api/GetMessagesBetweenPlaces — *Route corridor query*
operationId: GetMessagesBetweenPlaces
Query params: StartLat, StartLng, EndLat, EndLng, RouteName?, includePath?
Response: 200, FeatureCollection
- **POST** /api/GetMessagesIntersectingGeometry — *Spatial intersect query*
operationId: GetMessagesIntersectingGeometry
Request Body: IGeometryObject
Response: 200, FeatureCollection

Delete/Expire TIMs

- **DELETE** /api/delete-by-id/{id} — *Delete TIM by database id*
operationId: DeleteById
Path: id: string
Responses: 204, 400, 401, 403, 404, 500
- **DELETE** /api/delete-by-recordId/{recordId} — *Delete TIM by recordId*
operationId: DeleteByRecordId
Path: recordId: int32
Responses: 204, 400, 401, 403, 404, 500

Validator (For Troubleshooting)

- **POST** /api/decode — *Validate an encoded message*
operationId: Decode
Request Body: DecodeRequest { encodeType: hex|base64|uper, encodedMsg, messageType? }
Response: 200, DecodeResponse { messageType, decodedMessage }; 400, 401, 500

ICD Binding Notes

- For TIM lifecycle, the CTW Program uses /api/deposit and /api/delete-by-recordId as the normative write/delete paths; query operations are for discovery and audit.
- estimatedRemovalDate will be used to set validTo; if omitted, producers must send a subsequent delete or update.

Kafka Interfaces (Event Reports)

Broker and Namespaces

- **Bootstrap Servers:** kafka.sdx.ctw.gov:9093 (example placeholder).
- **Schema Registry:** schemareg.sdx.ctw.gov:8081 (if used).
- **Security:** mTLS (client cert CN maps to principal) or SASL/OAuth; TLS required.

Topic Naming

ctw.sdx.events.<jurisdiction>.<eventType>.v1

ctw.sdx.events.all.<eventType>.v1

- **Examples:** ctw.sdx.events.UT.congestion.v1, ctw.sdx.events.all.wrong_way.v1

Keys and Partitioning

- **Key:** eventId (UUID) for event reports
- **Partitions:** ≥ 6 per high-volume topic (TBD after sizing)
- **Compaction:** Disabled for append-only event history topics; enabled only for stateful streams if defined (not used for TIMs in CTW scope)

Serialization

- **Format:** Avro or JSON. If Avro, register event report schemas and versions. (subject=ctw.sdx.events.EventReport.v1).
- **Compatibility:** Backward-compatible evolution required for Event Reports.

Event and TIM Schemas (Normative) Event and TIM Schemas (Normative)

```
{  
  
  "$schema": "https://json-schema.org/draft/2020-12/schema",  
  
  "$id": "ctw.sdx.events.EventReport.v1",  
  
  "title": "CTW Event Report",  
  
  "type": "object",
```

```

"additionalProperties": false,

"required": ["event_id", "source", "event_type", "geojson", "start_tmstp_utc", "end_tmstp_utc"],

"properties": {

  "event_id": {"type": "string", "minLength": 1},

  "source": {"type": "string", "minLength": 1},

  "event_type": {"type": "string", "minLength": 1},

  "geojson": {

    "type": "object",

    "required": ["type", "coordinates"],

    "properties": {

      "type": {"type": "string", "enum": ["Point", "LineString", "Polygon"]},

      "coordinates": {"type": "array"}

    }

  },

  "event_metadata": {"type": "object"},

  "start_tmstp_utc": {"type": "string", "format": "date-time"},

  "end_tmstp_utc": {"type": "string", "format": "date-time"},

  "version": {"type": "string"}

}

{

{

  "$schema": "https://json-schema.org/draft/2020-12/schema",

  "$id": "ctw.sdx.tims.TimEnvelope.v1",

  "title": "CTW TIM Envelope",

  "type": "object",

```

```
"additionalProperties": false,

"required": ["timId", "issuer", "validFrom", "payload"],

"properties": {

  "timId": {"type": "string"},

  "issuer": {"type": "string", "enum": ["UDOT", "WYDOT", "CDOT"]},

  "validFrom": {"type": "string", "format": "date-time"},

  "validTo": {"type": "string", "format": "date-time"},

  "priority": {"type": "integer", "minimum": 0, "maximum": 9},

  "geometry": {"type": "object"},

  "payload": {

    "oneOf": [

      {"type": "string", "description": "Base64-encoded J2735 TIM (UPER)"},

      {"type": "object", "description": "Structured TIM (per SDX Swagger)"}

    ]

  }

}
```

- **Schema Registry Subjects (examples):**
 - ctw.sdx.events.EventReport.v1
 - ctw.sdx.tims.TimEnvelope.v1
- **Compatibility Mode:** backward (new fields optional; no breaking removals/renames).

Error Handling and Retries

- **Kafka Producers:** Retries with backoff, enable.idempotence=true, acks=all.
- **Kafka Consumers:** Commit offsets after successful processing; poison-message strategy (dead-letter topics) configured per topic: ctw.sdx.dlt.events.v1.

Monitoring and Metrics

- Producer/consumer lag, throughput, error rates.

- Broker health, topic partition ISR, disk utilization.
- Schema compatibility checks on deploy.

Field-Level Mappings

Event Report to SDX Transport

Table A-7 identifies the CTW event report fields and the use of each field by the SDX.

Table A-7. Event Report Object Fields

Source: Trihydro, 2025

CTW Event Field	Type	Required	SDX Transport Usage	Notes
event_id	string	Yes	Kafka key and payload field	Idempotency and ordering within partitions
source	string	Yes	Header x-ctw-source (optional) and payload	Producer identity/attribution
event_type	string	Yes	Header x-ctw-event-type (optional) and payload	Filtering/routing
geojson	object	Yes	Payload	WGS84; Point/LineString/Polygon
event_metadata	object	No	Payload	Forward-extensible map
start_tmstp_utc	date-time	Yes	Payload	International Organization for Standardization (ISO)-8601 Coordinated Universal Time (UTC)
end_tmstp_utc	date-time	Yes	Payload	ISO-8601 UTC
version	string	No	Header x-ctw-producer-version (optional) and payload	Analytics/evolution

TIM Envelope to SDX API Model

Table A-8 identifies the API object field definitions that are used in TIM retrieval.

Table A-8. SDX API Object Field Definitions for TIM Retrieval

Source: Trihydro, 2025

TIM Attribute	Type	Required	SDX Field	Notes
timId	string	Yes	timId	Unique per issuer

TIM Attribute	Type	Required	SDX Field	Notes
issuer	enum	Yes	issuer	UDOT/WYDOT/CDOT
validFrom/validTo	datetime	Yes	validFrom/validTo	ISO 8601
geometry	object	No	geometry	GeoJSON/J2735 ref
payload	string/object	Yes	payload	UPER b64 or structured

Error Codes and Response Contracts (REST)

This section normalizes common responses across SDX TIM endpoints used by the CTW Program. Table A-9 defines typical causes and explanations for error codes encountered through SDX exchanges.

Table A-9. Possible Return Codes from SDX API

Source: Trihydro, 2025

HTTP	Meaning	Typical Cause	Contract/Body
200	OK	Successful query/deposit summary	int32 (recordId) or JSON model per endpoint
204	No Content	Successful delete or no document	Empty
400	Bad Request	Invalid recordId, invalid geometry/query, invalid encoded message	ProblemDetails { type,title,status,detail,instance } or string
401	Unauthorized	Missing/invalid credentials or GeoJSON validation flag	ProblemDetails or string
403	Forbidden	Caller/org not authorized for region/action	ProblemDetails or string
404	Not Found	TIM does not exist	ProblemDetails or string
409	Conflict	Duplicate WZDx cosmos_id (WZDx endpoints)	ProblemDetails
500	Internal Server Error	Server failure	ProblemDetails or string

Models referenced: DepositRequest, DepositRequestList, DepositMultiSummary, AdvisorySituationDataDeposit, MessageFrame, RecordIdRequest, Query, FeatureCollection, ProblemDetails, DecodeRequest, DecodeResponse (see Swagger link in CTW Traveler Information Message (TIM) Documentation Version 1.0: Use of the TravelerInformation Structure to Build Standard Traveler Information Messages).

Non-Functional Requirements

- **Availability:** REST and Kafka ≥ 99.9% monthly for production.

- **Performance:** See the End-to-End Requirements section of this appendix for targets, load profile by corridor, and storm scenarios.
- **Scalability:** Horizontal scale of brokers and consumers; add partitions.
- **Observability:** Logs with correlation IDs, metrics, distributed tracing (OpenTelemetry recommended).
- **Data Quality:** Validation rules for mandatory fields; schema validation at ingress; rejection and Dead Letter Topic (DLT) process.

Testing and Validation

- **Contract Tests:** Swagger-based request/response validation.
- **Schema Tests:** JSON/Avro schema compatibility checks.
- **Integration Tests:** Kafka publish/subscribe with replay; end-to-end TIM lifecycle (publish, revoke).
- **User Acceptance Testing (UAT) Scenarios:** Cross-state event propagation; latency thresholds met.

ICD Appendices

Example Messages

// Example Event Report (fog) — illustrative only

```
{
  "eventId": "9a5ed0c2-3b3b-4c6b-b1a8-8f8c3aaf6c2e",
  "eventType": "fog",
  "jurisdiction": "WY",
  "status": "active",
  "createdAt": "2025-10-15T17:00:00Z",
  "location": {"type": "LineString", "coordinates": [[-105.1, 41.31], [-105.07, 41.33]]},
  "advisorySpeed": 45
}
```

// Example TIM Envelope (UPER as base64) — illustrative only

```
{
  "timId": "TIM-UDOT-000123",
```

```
"issuer": "UDOT",  
  
"validFrom": "2025-10-15T16:58:00Z",  
  
"validTo": "2025-10-16T01:00:00Z",  
  
"geometry": {"type": "Polygon", "coordinates": [[[-111.9,40.7],[-111.8,40.7],[-111.8,40.8],[-111.9,40.8],[-111.9,40.7]]]},  
  
"payload": "BASE64_UPER_TIM_HERE"  
  
}
```

SDX OpenAPI

The SDX OpenAPI JSON spec can be found on the [Swagger website for the SDX API specification](#).

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