Phase 1 Concept of Operations (ConOps)

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

www.its.dot.gov/index.htm

Final Report – September 8, 2026
FHWA-JPO-25-160

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

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-25-160		

4. Title and Subtitle	5. Report Date
Phase 1 Concept of Operations (ConOps) Vehicle-to-Everything (V2X) Accelerator Connecting the West – Utah Department of Transportation	September 8, 2026
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
D. Deeter, J. Schroeder, S. Zumpf, T. English, D. Weibler, L. Cordova, J. Amidon, L. Preisen, B. Leonard, P. Castro	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Utah Department of Transportation 2060 South 2760 West Salt Lake City, UT 84104	Proj No F-ST99(1014)
	11. Contract or Grant No. 693JJ324NF00003

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590	Final
	14. Sponsoring Agency Code HOIT-1

15. Supplementary Notes

16. Abstract

The Connecting the West (CTW) Program is one of three Vehicle-to-Everything (V2X) Accelerator sites awarded contracts by the Federal Highway Administration (FHWA) in 2024 through the United States Department of Transportation's (USDOT) Saving Lives with Connectivity: Accelerating Vehicle-to-Everything (V2X) Deployment grant 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.

This Concept of Operations (ConOps) document is a key step in the planning and design portion of the CTW Program. This document defines the challenges that the three member states face, overall objectives of the CTW Program to address these challenges, stakeholders, stakeholder needs, the system concept, and operational scenarios.

17. Keywords	18. Distribution Statement
V2X; Vehicle-to-Everything; Accelerator; Deployment; Intelligent Transportation Systems	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	103	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Acknowledgements

The Connecting the West (CTW) team would like to thank FHWA and Noblis for their technical assistance throughout the webinars and review sessions relating to the development of this document. The CTW team greatly appreciates the guidance from the walkthrough and subsequent input that shaped this version of the Concept of Operations (ConOps) document.

Table of Contents

1. Scope and Overview 1
1.1. Purpose and Document Overview 1
1.2. Scope 2
1.2.1. Program Boundaries 2
1.2.2. Areas Addressed 3
1.2.3. Limitations 3
1.3. Background 4
2. CTW Program Goals 7
3. Referential Systems 9
3.1. Current System Overview 9
3.1.1. Current System Functions 9
3.1.2. Current System Interoperability and Compatibility 10
3.1.3. Current System Scalability 11
3.2. Utah Current Systems 12
3.2.1. Utah Connected Intersections 12
3.2.2. Utah V2X Connected Roadways 15
3.2.3. Utah Vulnerable Road User Safety Systems 17
3.2.4. Utah Existing C-V2X Systems Schematic 19
3.3. Wyoming Current Systems 20
3.3.1. Wyoming V2X Connected Roadways 20
3.3.2. Wyoming Existing C-V2X Systems Schematic 22
3.4. Colorado Current Systems 23
3.4.1. Colorado Connected Intersections 23
3.4.2. Colorado V2X Connected Roadways 24
3.4.3. CDOT Existing C-V2 X Systems Schematic 26
3.5. Relationship to Other Systems 27
4. Justification for and Nature of Changes 29
4.1. Challenges to be Addressed by the CTW Program 29
4.1.1. Signalized Intersection Challenges 29
4.1.2. Interstates and Rural Corridors Challenges 30
4.1.3. Vulnerable Road Users Challenge 30
4.1.4. Interoperability and Compatibility Challenges 30
4.1.5. General Challenges 31

4.2. User Needs 31
4.2.1. User Classes and Other Involved Personnel 31
4.2.2. User Needs 32
4.3. Description of Desired Changes 38
4.4. Alternatives Considered 40
4.5. Priorities Among Changes 40
4.6. Changes Considered and Not Included 41
5. Operational Concepts 43
5.1. CTW Program Objectives 43
5.2. Operational Policies and Constraints 47
5.3. Description of the Proposed System 49
5.3.1. Functions of the Proposed System 51
5.3.2. Interfaces to External Systems 55
5.4. Modes of Operations 56
6. Operational Scenarios 59
6.1. Connected Intersection Issuing Preferential Treatment 60
6.2. Vehicle Equipped with Original Equipment Manufacturer Red Light Violation Warning Application 61
6.3. Spot Weather Impact Warning 63
6.4. Adjacent State Coordination – Wyoming I-80 Road Closed to Commercial Vehicles 66
6.5. Variable Speed Limits 68
6.6. Driver Warning of Vulnerable Road User Conflict at a Signalized Intersection 70
7. Summary of Impacts 73
7.1. Operational Impacts 73
7.2. Organizational Impacts 73
7.3. Impacts During Development 74
8. Analysis of Proposed System 75
8.1. Summary of Improvements 75
8.2. Disadvantages and Limitations 76
8.3. Alternatives and Trade-offs Considered 77
9. Original User Classes and User Needs for Legacy Systems 79
10. References 95

List of Tables

Table 1. CTW User Classes 32
Table 2. User Needs for the CTW System Mapped to Challenges 33
Table 3. CTW Objectives Related to Signalized Intersections 43
Table 4. CTW Objectives Related to Interstates and Rural Corridors 45
Table 5. CTW Objectives Related to Vulnerable Road Users 46
Table 6. CTW Objectives Related to Interoperability and Compatibility 46
Table 7. CTW Objectives Related to All Focus Areas 47
Table 8. Operational Scenario for a Connected Intersection Issuing Preferential Treatment 60
Table 9. Operational Scenario for a Connected Intersection Supporting In-Vehicle Safety Applications 61
Table 10. Operational Scenario for Spot Weather Impact Warning 63
Table 11. Operational Scenario for Adjacent State Coordination – Wyoming I-80 Road Closed to Commercial Vehicles 66
Table 12. Operational Scenario for Variable Speed Limits 68
Table 13. Operational Scenario for Driver Warning of Vulnerable Road User Conflict at a Signalized Intersection 70
Table 14. Proposed System Concept Elements and Benefits 75
Table 15. Original User Classes 79
Table 16. Original User Needs for Signalized Intersections 81
Table 17. Original User Needs for Interstates and Rural Corridors 84
Table 18. Original User Needs for Vulnerable Road Users 91
Table 19. Original User Needs for Interoperability and Compatibility 92

List of Figures

Figure 1. Utah Existing System of Interest Physical Architecture 19
Figure 2. Wyoming Existing System of Interest Physical Architecture 22
Figure 3. Colorado Existing System of Interest Physical Architecture 26
Figure 4. CTW Program System of Interest 50

List of Acronyms and Abbreviations

API	Application Programming Interface
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management System
BSM	Basic Safety Message
C-V2X	Cellular V2X
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CCD	City and County of Denver
CDOT	Colorado Department of Transportation
CI	Connected Intersection
CIMMS	Connected Intersection Message Monitoring System
CIPT	Connected Intersection Preferential Treatment
CMV	Commercial Motor Vehicle
ConOps	Concept of Operations
COTS	Commercial Off the Shelf
CSW	Curve Speed Warning
CTI	Connected Transportation Interoperability
CTIC	Connected Transportation Interoperability Committee
CTW	Connecting the West
CV	Connected Vehicle
CV PFS	Connected Vehicle Pooled Fund Study
DOT	Department of Transportation
ECLA	External Control Local Application
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
GCP	Google Cloud Platform
GHz	Gigahertz
GM	General Motors
GPS	Global Positioning System
HMI	Human Machine Interface
IC	Interoperability and Compatibility
IOO	Infrastructure Owner-Operator
IRC	Interstate and Rural Corridor
ISS	Integrity Security Services
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
LiDAR	Light Detection and Ranging

MAP	MAP Data Message
MDC	Mobile Data Computer
MS	Milliseconds
NTRIP	Networked Transport of RTCM via Internet Protocol
OBP	On-Board Processor
OBU	On-Board Unit
ODE	Operational Data Environment
OEM	Original Equipment Manufacturer
OTA	Over the Air
PFS	Pooled Fund Study
PMP	Project Management Plan
PoE	Power over Ethernet
REST	Representational State Transfer
RLVW	Red Light Violation Warning
RSU	Roadside Unit
RTCM	Radio Technical Commission for Maritime Services
RWIS	Road Weather Information System
SCM	Signal Command Module
SCMS	Security Credential Management System
SDSM	Sensor Data Sharing Message
SDX	Situation Data Exchange
SEMP	Systems Engineering Management Plan
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
SWIW	Spot Weather Impact Warning
SyRS	System Requirements Specification
TIM	Traveler Information Message
TIS	Traveler Information System
TMC	Traffic Management Center
TOC	Traffic Operations Center
TSCBM	Traffic Signal Control Basic Message
TSP	Transit Signal Priority
UDOT	Utah Department of Transportation
USDOT	United States Department of Transportation

UTA	Utah Transit Authority
V2I	Vehicle to Infrastructure
V2X	Vehicle-to-Everything
VM	Virtual Machine
VRU	Vulnerable Road User
VSL	Variable Speed Limit
WTI	Wyoming Traveler Information System
WYDOT	Wyoming Department of Transportation
WZDx	Work Zone Data Exchange

1. Scope and Overview

This document is the Concept of Operations (ConOps) for the Connecting the West (CTW) Program. The CTW Program is part of the United States Department of Transportation's (USDOT)'s 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. The CTW Program is led by the Utah Department of Transportation (UDOT) with partners Wyoming Department of Transportation (WYDOT) and Colorado Department of Transportation (CDOT). The CTW Program 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 (CV) 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.

The CTW Program will follow an incremental and iterative development process, structured around the systems engineering "Vee Model." This approach ensures seamless transition from conceptualization to operations, with iterative refinement at each phase. A Project Management Plan (PMP) has been developed and will be updated, as needed, throughout the CTW Program. A Systems Engineering Management Plan (SEMP) has also been developed. Finally, a detailed schedule has been developed to reflect the key milestones, tasks, and dependencies in alignment with the Phase 1 deliverables.

This ConOps document is a key step in the planning and design portion of the CTW Program.

1.1. Purpose and Document Overview

The purpose of this ConOps is to document user needs that the CTW Program will address and describe the proposed system from a user perspective, including use cases, operational concept, and scenarios. This ConOps describes:

- The current Cellular V2X (C-V2X) systems that the three states operate. In this document, C-V2X refers to the 5.9 Gigahertz (GHz) direct communications except when otherwise noted.
- The challenges that are intended to be addressed through this effort.
- The user needs that need to be addressed to overcome the challenges that are to be addressed by this effort.
- The overall objectives of the CTW Program.
- The new or improved capabilities needed to accomplish the objectives.
- A high-level description of the proposed system of interest with a summary of the functions.
- The stakeholders involved.

The user needs, capabilities, and functions described herein will be used to develop the system requirements in the task to develop the Systems Requirements Specification (SyRS).

The intended audience for this ConOps document is the United States Department of Transportation (USDOT); FHWA; the CTW Program partners, UDOT, CDOT, WYDOT, City and County of Denver (CCD), Utah Transit Authority (UTA), Salt Lake City, and General Motors (GM); and the consultants and contractors that are developing technical materials for the CTW Program.

1.2. Scope

The CTW Program boundaries, areas addressed, and limitations are described in this section to provide the overall scope.

1.2.1. Program Boundaries

CTW is a partnership between state and selected local agencies in the three member states, together with FHWA. Ultimately, a “System of Systems” will operate with ownership of individual systems within each state but, through collaboration among the three CTW sites and the additional V2X Accelerator program sites, will achieve interoperability and consistency.

CTW will not build a new system from the ground up; it will extend and enhance the proven systems in member states and knit them into a cohesive, interoperable network across the three states. Therefore, CTW activities are divided into two categories:

1. **Expansion of Legacy Systems**. Existing C-V2X systems will be expanded with the original functionalities and specifications previously defined. For these expansions, the systems engineering process will not revisit or re-engineer these systems. The focus will be on defining needs for expansion, requirements for accomplishing the needed expansions, and implementing the procurement and installation processes to expand the systems. The functions and physical systems of these legacy systems will be included in the CTW architecture but will not be detailed in either the System Architecture Document or System Design Document.
2. **Additions of New Functionalities**. CTW has identified needs for application integration and interoperability, both within the CTW states and nationally, and new functionality will be added to accomplish this. For these additions, the systems engineering process will define the needs, requirements, architecture, and design of any needed expansion of existing systems to meet these new functionalities, and project efforts will implement procurement and installation processes to accomplish these new functions.

To support these activities, this document will define user needs for the expansion of legacy systems and needs for the addition of new functionalities related to application integration and interoperability. Subsequent documents will then define requirements, a system architecture design, and a system design document for the additions of new functionalities. Following the Planning and Design tasks, materials and equipment will be procured, installed, tested, and operated. Collectively, these will comprise the subsystems that make up the overall CTW system of systems. As noted in the PMP, acquisition activities will begin before the conclusion of the Planning and Design tasks.

However, the CTW Program is not creating an overarching entity or prescribing actions on the member states. Individual subsystems operated by UDOT, WYDOT, and CDOT (as well as some local agencies) will carry on operations of the CTW-defined system of systems within their own agencies.

The partner agencies in CTW recognize the need for security in messages broadcast and the role that a Security Credential Management System (SCMS) plays in securing these messages. Each of the CTW states use an SCMS, and the extent to which there is interoperability within and between SCMSs and services will be an emphasis of this effort.

1.2.2. Areas Addressed

The CTW Program is focused on saving lives and improving mobility using V2X technology in the 5.9 GHz "safety spectrum" along with network communications platforms throughout Utah, Wyoming, and Colorado. CTW is multidimensional in that not only does it describe systems to support three states, but it also describes systems to address four focus areas:

- **Focus Area #1: Signalized Intersections (SIs).** This effort will address user needs related to SIs by installing Roadside Units (RSUs) and supporting Field Equipment at SIs, collectively referred to as ***Connected Intersections (CIs)***. These CIs will be enabled with appropriate messages and applications.
- **Focus Area #2: Interstate and Rural Corridors (IRCs).** This effort will address user needs related to IRCs by installing RSUs and supporting Field Equipment along Interstates and other highways, collectively referred to as ***V2X Connected Roadways***, and through network communications data exchanges to reach travelers using mobile applications. These V2X Connected Roadways and network communications will be enabled with appropriate messages and applications.
- **Focus Area #3: Vulnerable Road User (VRU) Safety at SIs.** This effort will address user needs related to VRUs at intersections by expanding the existing pilot in Utah that detects VRUs crossing intersections and alerts drivers through a combination of C-V2X communications and activation of blank-out signs. Note that while workers in work zones are also recognized as VRUs that may benefit from CTW activities, the detection of workers is not something being pursued in this program.
- **Focus Area #4: Application Interoperability and Compatibility (IC).** This effort will address user needs related to the interoperability of message type and content, security, and portability to 5.9 GHz On-Board Units (OBUs) and cellular CVs and VRUs and compatibility through collaboration, consensus building, and development of agreed clarifications and uses of national standards.

1.2.3. Limitations

An overarching limitation is that all ongoing operations of systems expanded upon or introduced in this process will be operated and maintained by the agency where they are deployed. This will be a key factor in determining the design, deployment, maintenance, and operations of systems. Each CTW agency has its own program and may have existing documents. The CTW team has produced this ConOps as a single document that covers the work performed for this grant program and includes input from individual states. Individual agencies are not completing their own ConOps as a part of this program.

A recent Federal Communications Commission (FCC) ruling adopting the Second Report and Order may require changes to V2X communication protocols or hardware, which could potentially affect deployment timelines.

1.3. Background

Improving safety, mobility, and operations effectiveness are fundamental goals for any transportation agency and are reflected in the goals of the CTW Program. Specifically, the activities for this effort are rooted in the existing challenges encountered by the CTW agencies and the traveling public in two areas: improving safety and improving mobility operations effectiveness, as described below.

Improving Safety. First, saving lives is an overall goal of this program. An unacceptable number of crashes and fatalities occur, specifically at SIs and along IRCs as well as in work zones, at curves, and during inclement weather conditions.

The concept is that with data communicated by the infrastructure, a number of safety applications can be created to support safety for drivers. The Red Light Violation Warning (RLVW) application is one example of an existing vehicle safety application that may help improve safety by influencing drivers approaching an SI to avoid entering the intersection during a red signal phase. The expected impacts of RLVW applications are described in the RLVW Concept of Operations developed by the Crash Avoidance Metrics Partnership (CAMP) as most likely to impact distracted or inattentive drivers as well as drivers not familiar with the intersection and uncertain if they should proceed during a yellow signal indication (CAMP LLC Vehicle-to-Infrastructure [V2I-4] Consortium, 2021).

Even with a limited number of RLVW applications in operation, the potential for safety improvements exists. The role of Infrastructure Owner-Operators (IOOs) is to operate CIs that are validated to be accurate and reliable in meeting requirements defined by the Connected Transportation Interoperability (CTI) family of standards (Institute of Transportation Engineers [ITE], n.d.). The CTI family of standards includes a series of documents jointly developed by stakeholders representing IOOs automotive industries, device manufacturers, mobility data providers, and system integrators that provide guidance to develop and maintain CV interoperability. After receiving timely information from validated CIs, the application can help improve safety by issuing in-vehicle warnings to drivers that may reduce the number of times that drivers unintentionally enter SIs when the traffic signal indication is red (e.g., due to distracted driving).

Travelers along IRCs are vulnerable to inclement weather, stopped traffic, and other hazards. Dissemination of standardized traveler information messages (TIMs) through RSUs is an existing application that may improve safety for vehicles equipped with OBUs to receive the messages. When supplemented by disseminating these same messages through network cellular communications to inform travelers using third-party traveler information systems, more travelers will receive the messages. Again, interoperability will be key to enabling applications to use TIMs broadcast by different jurisdictions such that the in-vehicle applications work seamlessly as the vehicles travel through various states.

This effort will also address crashes involving vehicles and VRUs. The Concept for System Capabilities: Vulnerable Road User Safety Systems (Panasonic, n.d.) describes VRUs as the following: “VRUs include walkers, joggers, runners, cyclists, micro mobility and others that are within or traveling on roadways shared by motor vehicles.” Delivering information to the driver about the presence of VRUs may

significantly improve safety at both SIs and work zones. This approach will be referred to as VRU Safety Systems. Research conducted for UDOT suggests that the biggest contributing factor of crashes involving VRUs was the failure of the driver to yield the right of way (Panasonic, n.d.).

Improving Mobility and Operations Effectiveness. Agency fleet vehicles that approach SIs during red signal phases can cause significant disruptions to the mobility and operations effectiveness of these vehicles. Transit vehicles regularly experience delays that impact route performance, rider mobility, and transit agency operations costs. Snowplows are critical in removing snow and treating road surfaces for ice. The faster that plow vehicles can clear roads, the sooner that the mobility of passenger vehicles, transit vehicles, and emergency vehicles can be improved while also reducing agency operations costs for snow removal.

Stopping at SIs is especially challenging for snowplows as it disrupts the movement of snow and often disrupts plow effectiveness at the intersection approaches when pavement conditions are critical. The transportation network is also used by emergency responders that include law enforcement, fire, and ambulance services. SIs present challenges to these responders as they must navigate the intersection as quickly as possible while other vehicles are often present. The operations' effectiveness expands beyond mobility benefits and introduces possible benefits to sustainable travel impacts. In all cases, but particularly with buses and plow vehicles, idle times at SIs can also contribute to adverse air quality impacts.

Travelers on IRCs can experience adverse mobility for any number of conditions. For example, delays due to work zones, weather, or incidents can cause significant delays that impact the traveling public, including long-haul freight carried by commercial motor vehicles (CMVs). CMV drivers may also struggle to find truck parking along key freight corridors and the surrounding areas, particularly when downstream road closures occur due to severe weather conditions like snow and ice or high winds. The lack of information about available truck parking can cause uncertainty for CMV drivers about finding parking at the end of their allotted drive time.

2. CTW Program Goals

This section describes the goals that drive the activities of the CTW Program and reflect the high-level needs that were the basis for initiating this effort. Additionally, a set of candidate performance metrics and preliminary targets are also presented in this section that reflect the CTW Program goals and will be the basis for an expanded evaluation to assess the effectiveness of the CTW Program after deployment and operations.

Improving safety, mobility, and operations effectiveness as well as advancing technology solutions are the fundamental goals of the CTW Program. Specifically, the CTW Program goals are:

- **CTW Goal #1:** To use interoperable V2X technologies to reduce the number of crashes and fatalities at intersections, in work zones, along rural corridors, in bad weather, and those involving VRUs.
- **CTW Goal #2:** To use interoperable V2X technologies to improve system operations and effectiveness of transit, emergency, and snowplow fleet vehicles to improve traveler mobility, improve safety, and reduce fuel costs.
- **CTW Goal #3:** To help advance solutions to three big picture systemic problems:
    - The need for national deployment of interoperable V2X systems, especially in the 5.9 GHz spectrum.
    - There is an industrywide challenge that the benefits of IOO-deployed infrastructure will not be fully recognized until there is a critical mass of C-V2X equipped vehicles, and similarly that the benefits to drivers of C-V2X-equipped vehicles will not be fully recognized until there is a critical mass of C-V2X-equipped roadside infrastructure. This is often referred to as a “chicken and egg” barrier that must be overcome to expand CVs to become deployed and operational at a large scale.
    - Automakers’ willingness to integrate systems will be critical for meeting safety and operational goals.

3. Referential Systems

An overview of the current system and relationship to other systems are described below.

3.1. Current System Overview

The three CTW partner states decided to collaborate on this program because they are geographically adjacent, have significant Interstate corridors in common, and each have extensive C-V2X experience that includes deployed and operational equipment. Most important, they all share the vision of expanding the operational systems and pilots to improve safety, mobility, and efficiency.

3.1.1. Current System Functions

From a high-level perspective, each CTW state has C-V2X deployments that are currently delivering tangible benefits to everyday operations. Additionally, each CTW state has C-V2X deployments that are pilots to test systems and explore the benefits that will be achieved as the geographic coverage of C-V2X increases and as the number of privately owned CVs eventually expand. These deployments are summarized as follows:

- C-V2X deployments at SIs (CIs):
  - UDOT operates 360 CIs that support transit signal priority (TSP) and signal preemption for snowplows and emergency vehicles. With over 300 transit vehicles, snowplows, and emergency vehicles currently participating, these CIs are fully integrated into operations of UDOT and UTA, delivering tangible benefits today. UDOT is also actively pursuing the goal of achieving timely, accurate, and reliable broadcasts of the critical data from their CIs to support original equipment manufacturer (OEM) and aftermarket safety applications. Through a recent Strengthening Mobility and Revolutionizing Transportation (SMART) grant, a pilot corridor has achieved this status and demonstrated the functionality to OEMs participating in the CTW Program.
  - CDOT operates 26 CIs that support snowplow preemption. With many of the CDOT Region 1 snowplows participating and benefitting from preemption, this system is integrated into operations and delivering tangible benefits today.
- C-V2X deployments along Interstates and rural and urban corridors (V2X Connected Roadways):
  - UDOT operates 53 RSUs along IRCs that broadcast TIMs describing alerts and warnings for passing CVs and collect data from the basic safety messages (BSMs) broadcast by CVs. With a small number of fleet vehicles equipped, these systems are primarily Connected Roadway pilots to test and improve the systems in preparation for eventual increases in privately operated CVs. Nonetheless, these systems deliver tangible benefits each time one of the public or private vehicles receives alerts while en route and presents it to the driver.

  - CDOT operates approximately 350 RSUs along CDOT-operated highways that broadcast TIMs and approximately 40 CDOT fleet vehicles that are equipped to receive TIMs and display the content as well as to broadcast BSMs. Similar to UDOT, these are primarily Connected Roadway pilots, but tangible benefits are delivered when one of those vehicles receives alerts while en route and presents it to the driver.
  - WYDOT has approximately 70 RSUs operational along WYDOT-operated highways that broadcast TIMs and collect BSMs. WYDOT also supplements the C-V2X RSUs by delivering TIMs to OBUs through Sirius XM satellite dissemination, effectively covering the entire WYDOT road network. WYDOT was a USDOT CV Pilot Deployment site and has legacy vehicles operating through that system. With the delivery of TIMs through the combination of RSUs, Sirius XM, and through the Situation Data Exchange (SDX), the WYDOT Connected Roadway deployment delivers key information to benefit travelers, especially commercial vehicle operators.

- VRU deployments at SIs:
  - UDOT has one intersections equipped with systems to warn drivers of possible conflicts with VRUs. This system is operating as a pilot and includes research activities to better understand the systems before further expansion.

Each of these deployments are supported by Central Systems (i.e., one or more subsystems operated at a central location), Field Equipment (i.e., equipment at the roadside), and Vehicle Systems (i.e., one or more on-board devices). The remainder of this section describes aspects of these systems and subsystems that are germane to the proposed system described in later sections. The term system of interest (SOI) is used to represent those systems and subsystems that collectively comprise the overall C-V2X system and to represent what systems are external systems to the SOI. External systems perform a supporting role to the systems in the SOI but are not considered part of the C-V2X SOI.

3.1.2. Current System Interoperability and Compatibility

A common trip for commercial or leisure travelers includes travel along I-80 through Utah and Wyoming, combined with travel on I-25. In this example, over the course of a day of travel, the drivers operating CVs could receive human machine interface (HMI) reports of warnings and alerts generated by each of the CTW states. The extent to which the Vehicle Systems successfully communicate to receive and send messages and the extent to which the content is consistent and consistently delivered to the Vehicle System are examples of what is referred to as interoperability and consistency in C-V2X. Similarly, as production vehicles begin to include RLVW applications, each of those vehicles may pass through hundreds or thousands of different intersections over the life of the vehicle, broadcasting the data needed to support the issuance of warnings. These applications need consistency in the data received to function properly.

The CTW member states share some basic consistencies, such as the common use of SAE J2735 messages, the common use of some RSU and OBU vendors, and some overlap in the vendor software systems between CDOT and WYDOT. However, there are some key differences that are barriers to interoperability and consistency, such as:

- **TIM Structure Consistency.** While each state is generating TIMs, there is not a common approach to formulating the TIMs. Because vendor OBUs typically process TIMs and deliver content to an HMI, consistency in TIMs across agencies nationwide is required for maximum benefits.

- **Event Report Content Consistency.** The underlying content used in creating TIMs are event reports (e.g., work zones, incidents, closures, driving conditions, etc.). While each of the CTW member states report and track event reports, the approach to event reporting is not universal within these states or nationwide in terms of what conditions warrant a TIM (e.g., the type of content to include within the TIM or the TIM valid area).
- **CI Consistency.** CDOT and UDOT both operate CIs, as do many other public agencies across the United States. Prior to the concerted efforts of the Connected Transportation Interoperability Committee (CTIC) Program supplemented by work of the Connected Vehicle Pooled Fund Study (CV PFS) and UDOT SMART Grant, there was no clear authoritative guidance regarding interpreting and validating the SAE J2735 standards that related to CIs. With this clarification, there is now a clear path for agencies to achieve consistency. The industry currently has a number of different traffic signal controller vendors and different versions of controllers in operations that are challenges to interoperability. These challenges include the fact that some signal controllers have been observed to not provide accurate data through the external interface that is designed to accurately describe what is displayed on the signal lights, making it impossible for the CI aspect of the intersection to accurately describe the signal status. The extent of these issues (e.g., whether it impacts all versions of these vendors' signal controllers or just limited versions or the extent of all signal controllers that have this issue) is not uniformly understood in the industry or even in the controllers in Utah. The challenge can be summarized by noting that these signal controllers are fundamental to the operation of the SI, and the ability to replace all signal controllers is not feasible. Therefore, the challenge will only be overcome if the existing signal controller manufacturers update their systems to output data that accurately represents the traffic signal phases consistently.

3.1.3. Current System Scalability

The structure of the current system deployments in CTW member states and use of established SAE standards is very conducive to scalability and expansion. Examples demonstrating this include:

- **TIM Generation**. The Central Systems generating TIMs process data inputs and generate TIMs. If there are data describing events and conditions for expanded geographic areas, expanded content, and/or additional road classifications, the ability for Central Systems to support addition TIM creation is very scalable.
- **TIM Delivery.** The operations of RSUs, satellite radio, or network cellular to communicate TIMs to CVs is also very scalable. Because RSUs typically receive and broadcast TIMs, they are relatively routine to deploy and will support the expanded TIMs.
- **Connected Intersection Preferential Treatment (CIPT).** In areas where CIs are supporting preferential treatment for authorized vehicles, the systems are fully expandable and do not rely on vendor product priority systems. The vehicles authorized to request priority or preemption can be expanded by equipping the public agency vehicles with needed Vehicle Systems. And as SIs are outfitted as Cis, they can immediately support preemption for any authorized vehicle.
- **Central Systems.** Experiences have shown that the Central Systems that support CIs and V2X Connected Roadways are expandable and that the algorithms for generating TIMs or monitoring health and operations of Field Equipment are scalable and not a limiting factor.

While scalability is promising, there are industrywide potential barriers to the scalability of these systems, including the following:

- **Infrastructure Costs.** The costs to deploy and operate RSUs are a possible barrier. However, where these are supporting operations (e.g., in the Utah and Colorado CIPT systems), they already are showing positive returns on investment. As the number of privately owned vehicles increases, these benefits of Connected Roadway RSUs will also increase substantially.
- **Private Vehicles Operating as CVs**. The long-term safety benefits of CIs and V2X Connected Roadways are dependent on the number of private vehicles equipped with CV safety applications.

In order to advance the interoperability, consistency, and scalability discussed above, it is critical to document and understand the current systems. Aspects of the current system are described below.

3.2. Utah Current Systems

Relevant systems currently deployed in Utah include CIs, V2X Connected Roadways, and VRU Safety Systems. Descriptions of these deployments are provided below.

3.2.1. Utah Connected Intersections

Utah currently operates 360 CIs that utilize V2X technologies to communicate with vehicles. The primary use of these CIs is currently to support preferential treatment for agency fleet vehicles (e.g., TSP and emergency vehicle and snowplow preemption). In addition to supporting preferential treatment, these CIs are also intended to support in-vehicle applications that rely upon Signal Phase and Timing (SPaT) and Map Data Messages (MAP) (e.g., RLVW). To this effect, a limited number of intersections have been evaluated against the requirements defined by the CTIC effort and validated to support RLVW applications. Finally, the CIs in Utah broadcast TIMs when these are created for roadway segments near the CI (details about the broadcast of TIMs are included in Section 3.2.2).

These Utah CIs involve three subsystems: Field Equipment, Central Systems, and Vehicle Systems. Descriptions of each of these subsystems are included below. External systems are also noted; while not part of the CIs, they are needed for the system to function.

3.2.1.1. Utah Connected Intersections: Field Equipment

The Utah CI Field Equipment consists of the following:

- **RSUs.** UDOT operates RSUs from vendors that include Kapsch and Commsignia. The RSUs broadcast and receive V2X messages using C-V2X communications. All of the RSUs are powered using Power over Ethernet (PoE) if the distance between the PoE Power injector and RSU is no greater than 100 meters. In most locations, the RSU is installed on a signal mast arm or luminaire pole that is located on the same corner as the cabinet that houses the signal controller, providing a simple and robust installation. The RSUs are secure and only broadcast messages with security credentials. The RSUs receive Signal Request Messages (SRMs) broadcast by C-V2X-equipped fleet vehicles, and these priority or preemption requests are passed through the signal command module (SCM) to the traffic signal controller. The RSUs also receive BSMs broadcast by Vehicle Systems and only retain and forward to Central Systems those messages with security credentials.

- **SCMs.** These are external control local application (ECLA) devices from Helix Innovations that are located in the signal controller cabinet and maintain a connection to the signal controller. The SCMs send MAP, SPaT, Signal Status Messages (SSMs), and (at some CIs) Radio Technical Commission for Maritime Services (RTCM) messages to the RSU to be broadcast.
    - SPaT messages broadcast are generated from information that the SCM receives from the traffic signal controller every 100 milliseconds (ms). The information from the signal controller currently is received as Traffic Signal Control Basic Message (TSCBM) format.
    - MAP messages are generated through a manual process at UDOT and uploaded to the RSU for the SCM to communicate to the RSU.
    - The SCM generates RTCM messages from either the SCM itself or by using a Networked Transport of RTCM via Internet Protocol (NTRIP) server. Currently, not every CI is broadcasting RTCM messages. The device processes the SRMs received by the RSU that contain requests for either priority (from transit buses) or preemption (from snowplows or emergency vehicles), and the SCM interfaces with the traffic signal controller to implement signal priority and preemption when warranted. As necessary, the SCM reports ongoing TSP and preemption requests by generating and sending SSMs to the RSU to broadcast.
- **Network Switches.** The network switches are PoE-enabled and support power cycles initiated by the Central System to reset the RSUs, as needed.
- **Fiber Connectivity.** Each RSU is connected to UDOT's fiber optic network, enabling communications with the Central System.

3.2.1.2. Utah Connected Intersections: Central Systems

Two components of the Utah Central System supporting CIs are as follows:

- **C-V2X Central System.** UDOT used the Cirrus platform developed by Panasonic up through late 2025 and will replace that system with the iNET platform developed by Parsons and Taplane in early 2026. These two platforms provide very similar capabilities; the transition does not represent any significant changes. This new system will be known as "Connected Utah." Although iNET has many Advanced Traffic Management System (ATMS) functions, UDOT will be leveraging only the V2X-related modules in iNET. While Cirrus was referenced in earlier versions of this ConOps, most of those references now reflect a more generic term: the UDOT V2X Maintenance Management System (V2X MMS), which includes both Cirrus and iNET / Connected Utah. The V2X MMS interfaces with and receives messages from the field via RSUs. Each RSU is connected to the UDOT network, which allows data traffic to and from the V2X MMS network via firewall configurations. The in-place UDOT RSUs are secured and therefore only forward messages from OBUs that have valid security credentials. The public agency-owned OBUs broadcast BSMs with rotating vehicle IDs that do not persist; therefore, the origin-designation of vehicle journeys is not collected. Access by UDOT staff to data stored by the V2X MMS is based on individual approved account permissions, with logging and monitoring of all user activities. The V2X MMS does not perform a role in determining if priority or preemption is to be granted.
    - Specific roles performed by the V2X MMS to support CIs include:
        - Uploading MAP messages (new or updated) to the RSU. MAP messages are manually created and edited/updated as needed and new versions are uploaded to the RSU.

        - Collecting and storing the BSMs and SRMs received by the RSUs at the CIs.
        - Collecting and storing the messages broadcast by the RSUs (i.e., SPaT, MAP, RTCM, and SSM).
        - Providing monitoring and operational support for the CIs to maintain operations.
    - No new system additions or changes were performed as part of the CTW Program.
- **Connected Intersection Message Monitoring System (CIMMS).** Some Utah CIs interface with CIMMS, enabling CIMMS to access messages that include BSMs, SPaT, and MAP. CIMMS is a message monitoring system developed by the CV Pooled Fund Study (PFS) that performs tests to identify conflicts and anomalies.

3.2.1.3. Utah Connected Intersections: Vehicle Systems

The vehicles currently performing two-way communications with the Utah CIs are public agency vehicles, specifically transit buses, emergency (fire and rescue) vehicles, and UDOT-operated snowplows. In addition, any vehicle passing by Field Equipment may receive the broadcasts and/or may be broadcasting the BSM.

The Vehicle Systems supporting the UDOT CIs include the following subsystems:

- **OBUs.** The OBUs equipped in the UDOT public agency vehicles receive and process messages broadcast by the RSUs and make the information available to the on-board processor. The OBU provides the Global Positioning System (GPS) data as well.
    - The messages received and processed by the OBUs include:
        - SPaT messages
        - MAP messages,
        - SSMs, and
        - RTCM messages.
    - The messages broadcast by the OBUs include:
        - SRMs. The SRMs convey requests for signal priority or preemption. The SRMs are formulated in the on-board processors (OBPs), as described below.
    - BSMs. The OBU pulls data from the vehicle through the controller area network (CAN) bus to populate portions of the BSM. The amount of data populated in the BSM depends upon the make/model/year of the vehicle. For some vehicles, only a portion of the BSM core data can be populated with actual data. For many vehicles, the BSM includes transmission state, vehicle speed, accelerator pedal position, brake pedal position, and ambient air temperature. On a smaller set of vehicles, the BSM includes wiper rate, hazard signal on, headlights on, turn signals on, and auxiliary brake status. On a very small set of vehicles, the BSM also includes latitude and longitudinal acceleration, steering wheel angle, yaw rate, and anti-lock brake status. The OBUs are designed for anonymity by rotating the vehicle ID associated with the vehicle. The OBUs have C-V2X communications capability and attach SCMS security certificates with each broadcast.
- **OBPs.** The OBPs are Linux-based processors that are equipped on the transit and emergency vehicles and snowplows. A key function of the OBP is to determine if the vehicle meets the eligibility to

request priority and to formulate the SRMs when they are eligible. For transit vehicles to request priority, the vehicle must have a minimum level of occupancy and must be at least 5 minutes behind schedule. For snowplows, whenever the salt/sand distributor is activated, the vehicle will broadcast requests for preemption for each CI it approaches.

- The OBP processes the MAP messages to determine the location of the intersection they are approaching and direction of travel. The vehicles determine their lane of travel; however, RTCM broadcasts are not required for the priority/preemption requests.
- The OBPs on transit buses also communicate with the vehicle's mobile data computer (MDC), which acts as a central hub for managing the vehicle's operations such as the route schedule and passenger data, and performs communications to central dispatch and other similar functions. The OBP obtains transit vehicle occupancy and reliability information from the MDC, enabling the OBP to determine whether or not to request priority.

3.2.1.4. Utah Connected Intersections: External Systems

The following are external systems to the Utah CIs:

- **Traffic Signal Controllers.** The traffic signal controller at each CI outputs the current status of the signal controller (i.e., which signal groups are in green, yellow, and red phases and the time to the next phase change) using the TSCBM. The signal controller maintains a time clock, and the TSCBM describes signal status in relation to this time clock. The signal controller also grants priority or preemption.
- **The NTRIP RTCM Source.** Currently, some Utah CIs access an NTRIP server for RTCM messages.
- **Integrity Security Services (ISS) SCMS Service.** All Utah CIs and OBUs broadcast secure messages.

3.2.2. Utah V2X Connected Roadways

Utah currently operates C-V2X RSUs and supporting Field Equipment along Interstates and rural and urban corridors that utilize V2X technologies to communicate with vehicles. The primary use of these deployments is to deliver warnings or alerts to CVs and to collect data from the CVs about current conditions. The vehicles currently participating in Utah's connected corridors consist of public agency vehicles that drive the corridors.

These V2X Connected Roadways consist of three subsystems: Field Equipment, Central Systems, and Vehicle Systems. Descriptions of each of these subsystems are included below.

3.2.2.1. Utah V2X Connected Roadways: Field Equipment

UDOT currently operates 92 C-V2X RSUs along IRCs that utilize V2X technologies to communicate with vehicles, including:

- 8 RSUs along SR-190 (Big Cottonwood Canyon Road)
- 36 RSUs along I-80
- 2 RSUs on I-15

- 2 RSUs on SR-201
- 1 RSU on I-215
- 2 RSUs on US-189
- 7 RSUs on US-89/91
- 7 RSUs on Provo Canyon Road
- 5 RSUs on US-189
- 1 RSU on I-70
- 17 RSUs on I-15
- 4 RSUs on US-40

The Utah V2X Connected Roadways Field Equipment consists of the following:

- **RSUs.** Along IRCs, UDOT operates RSUs from vendors that include Kapsch and Commsignia. The RSUs broadcast and receive V2X messages using C-V2X communications. In most locations, the RSUs are installed along the roadside on poles. The RSUs are secure and broadcast messages with security credentials. A summary of the messages exchanged at the RSUs is as follows:
  - TIM Messages.
    - The RSUs receive TIM messages from the Central System and broadcast these messages, typically at a frequency of 1 Hz.
    - The TIMs are delivered to the RSUs with “store and repeat” broadcast function.
    - The RSUs attach security credentials to the TIMs at the RSU before broadcasting.
  - BSM Messages.
    - The RSUs receive BSMs broadcast by Vehicle Systems and forward those messages to the Central System.
    - The RSUs only retain and forward to Central Systems those BSMs with security credentials.
- **Network Switches.** The network switches are PoE-enabled and support power cycles initiated by the Central System to reset the RSUs, as needed.
- **Fiber Connectivity.** Each RSU is connected to UDOT’s fiber optic network, enabling communications with the Central System.

3.2.2.2. Utah V2X Connected Roadways: Central Systems

UDOT operates the V2X MMS as the Central System to support V2X Connected Roadways (the same Central System supporting Utah’s CIs). The V2X MMS role in V2X Connected Roadways is as follows:

- The V2X MMS provides monitoring and operational support for the RSUs along IRCs, including storing the messages formulated for broadcast by the Field Equipment and storing the messages (and related data) received by the Field Equipment.

- The V2X MMS formulates TIM messages that are sent to the Field Equipment for broadcast. Examples of the TIM messages formulated and disseminated by the V2X MMS include:
    - TIMs that describe weather and driving conditions and curve speed advisories. The UDOT Advanced Traffic Management System (ATMS) generates TIMs and sends them to the V2X MMS.
    - TIMs that describe traffic events. To create these TIMs, the V2X MMS uses BSM data to create TIMs that describe certain traffic events.

3.2.2.3. Utah V2X Connected Roadways: Vehicle Systems

The CVs currently operating in the Utah V2X Connected Roadways are public agency vehicles, specifically snowplows, maintenance supervisor vehicles, and some other agency fleet vehicles equipped with OBUs. In addition, any private vehicle passing by Field Equipment may receive the broadcasts and may broadcast BSMs.

Current OBUs operated by UDOT include Commsignia and Ficosa. The functions of the OBUs include:

- **Generate and Broadcast BSMs.** A portion of the UDOT fleet is equipped with OBUs that broadcast BSMs. The BSMs are generated by the commercial OBU products without access to the CAN bus and, therefore, have a limited set of BSM data elements.
- **Receive and Process TIMs.** In a smaller number of UDOT fleet vehicles, OBUs in the Vehicle Systems receive TIMs through C-V2X communications, check the SCMS certificates, and make the TIMs accessible to drivers through HMI interfaces. These are primarily pilot deployments to test this functionality. The OBUs either include HMIs or connect to tablets that serve as the HMI.

3.2.2.4. Utah V2X Connected Roadways: External Systems

The external systems supporting Utah's V2X connected roadways include the data sources that are accessed to formulate the content of the TIMs that are delivered to RSUs and broadcast. These include:

- **UDOT RWIS Network.** UDOT's Road Weather Information System (RWIS) includes a network of weather stations throughout the state that typically includes atmospheric sensors and pavement sensors. The RWIS data is combined, made available to operators at the Traffic Operations Center (TOC), and accessed by the UDOT ATMS to support the creation of TIMs.
- **UDOT Advanced Traffic Management System (ATMS).** UDOT's ATMS includes reports of traffic incidents, work zones, work zone-related delays, and travel times. The ATMS generates TIMs that are used by the V2X MMS.

3.2.3. Utah Vulnerable Road User Safety Systems

UDOT is currently operating and pilot testing a VRU Safety System at one intersection in Salt Lake City, Utah at the intersection of SR 68 (Redwood Road) & 2100 South.

The subsystems for this existing VRU Safety System are provided below.

3.2.3.1. Utah VRU Safety Systems: Field Equipment

The Field Equipment for Utah's VRU Safety Systems include the following:

- **Light Detection and Ranging (LiDAR)-Based VRU Detection Systems.** UDOT is operating and pilot testing LIDAR-based detection systems to detect VRUs at intersections and generate warnings through an in-vehicle application and for display on a roadside sign at the intersection.
  - A pole-mounted LiDAR unit at the intersection detects and classifies vehicles and also detects and classifies VRUs.
  - A processing unit in an edge computer (located in a nearby cabinet) operates software that completes the following actions:
    - The processing unit currently creates Sensor Data Sharing Messages (SDSMs) that contain real-time data about VRUs crossing the intersection at the crosswalks, such as the VRU's position, speed, and heading, as well as information about vehicles approaching the intersection. The SDSMs are generated and sent to the RSU for broadcast at a frequency of 10 Hz.
    - The processing unit operates an algorithm that uses the LiDAR detection data (vehicles and VRUs) to predict potential collisions based on defined zones (right-turn zone and crosswalk zone) within the intersection, determines whether to activate the roadside blank-out sign, and triggers the sign activation as appropriate.
    - The processing unit creates TIMs that describe the conflict with the VRU. These TIMs are intended to warn drivers turning right that will cross the path of the crosswalk and have a valid region of the right-turn lane.
- **RSUs.** The RSU receives and broadcasts the SDSMs and TIMs.
- **Blank-Out Signs.** Blank-out signs located at the intersection receive an activation trigger message from the LiDAR-based VRU detection system and display a predetermined warning message to approaching vehicles.

3.2.3.2. Utah VRU Safety Systems: Central Systems

The V2X MMS serves as a Central System supporting the VRU Safety Systems at intersections. The role of the V2X MMS is as follows:

- Receive information describing the activations of the blank-out signs.
- Collect and store information about the SDSMs and TIMs generated and broadcast.
- Collect data on the health and operations of the RSU.

Currently, the health and operations of the LiDAR system are not monitored, but UDOT recognizes the need to monitor if the LiDAR is operational and whether the detection range is diminished for whatever reason (e.g., a lens that requires cleaning).

3.2.3.3. Utah VRU Safety Systems: Vehicle Systems

The Vehicle Systems associated with the UDOT VRU Safety Systems include:

- **OBUs**: A small number of UDOT fleet vehicles are equipped with Commsignia OBUs that support VRU Safety Systems.
  - The Commsignia OBU receives the SDSMs from the RSU through C-V2X communications.
  - The OBU processes the SDSMs with the OBU-generated vehicle location and direction and determines potential collisions between the vehicle and the VRU.
  - When a potential collision is determined, a warning notification is displayed to the driver through the OBU's HMI in the vehicle.
- **OBUs**: Other OBUs that are equipped to receive and display TIMs support the display of warning TIMs to vehicles in the right turn lane when a VRU is detected in the crosswalk.

3.2.3.4. Utah VRU Safety Systems: External Systems

The external systems that Utah VRU Safety Systems include:

- Vehicles not equipped with C-V2X communications. The CTW Field Equipment will interface with drivers of vehicles not equipped with C-V2X communications by activation of blank-out signs.

3.2.4. Utah Existing C-V2X Systems Schematic

The following schematic (Figure 1) illustrates the current Utah SOI that is related to the CTW Program, as is explained above in Sections 3.2.1, 3.2.2, and 3.2.3.

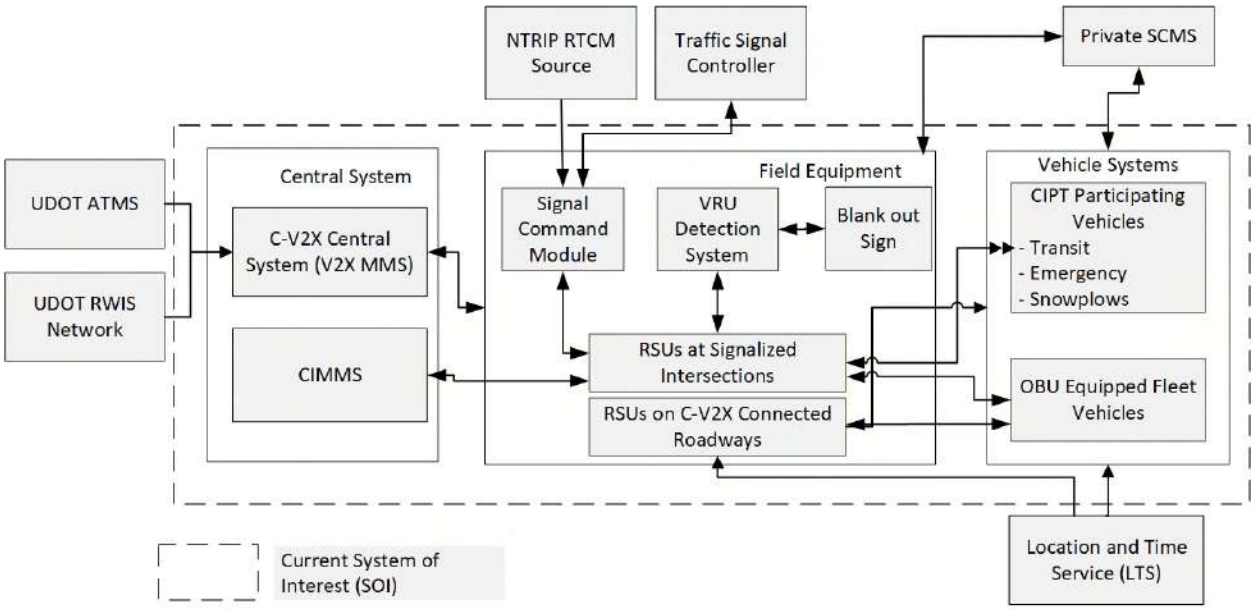

Figure 1. Utah Existing System of Interest Physical Architecture
Source: Athey Creek Consultants, February 2025

3.3. Wyoming Current Systems

Wyoming's relevant existing systems include V2X Connected Roadways.

3.3.1. Wyoming V2X Connected Roadways

Wyoming's existing systems operate as V2X Connected Roadways. Details about the systems and subsystems included in Wyoming's V2X Connected Roadways are provided in this section.

3.3.1.1. Wyoming V2X Connected Roadways: Field Equipment

WYDOT currently operates several C-V2X RSUs along IRCs that utilize V2X technologies to communicate with vehicles, including:

- 65 RSUs along I-80 across the state
- 1 RSU on I-80 Business in Evanston (near the Utah border)
- 1 RSU on US 191 near Rock Springs
- 1 RSU on US 287 in southeast Wyoming near Laramie
- 1 RSU on US 30 near Cheyenne
- 1 RSU on WY 13 near Medicine Bow National Forest
- 1 RSU on WY 72 near Saratoga

The Wyoming V2X Connected Roadways Field Equipment consists of the following:

- **RSUs.** Along IRCs, WYDOOT operates RSUs from Commsignia. The RSUs broadcast and receive V2X messages using C-V2X communications. The RSUs are connected through registered spectrum wireless, microwave, cellular, and fiber communications. The RSUs are secure and broadcast messages with security credentials. A summary of the messages exchanged at the RSUs is as follows:
    - The RSUs receive TIM messages from the Central System and broadcast these messages, typically at a frequency of 1 Hz. The RSUs attach security credentials to the TIMs at the RSU before broadcasting.
    - The RSUs also receive BSMs broadcast by Vehicle Systems and forward those messages to the Central System. The RSUs only retain and forward to Central Systems those messages with security credentials.
    - The RSUs are configured to forward transmitted and received SAE J2735 messages to a backend system, known as the Operational Data Environment (ODE). This system is hosted internally on WYDOT's virtual machines (VMs). WYDOT also supports over the air (OTA) updates, certificate updates, and V2X message log file offloading for OBUs via Wi-Fi through selected RSUs.

There are no additional supporting devices as part of the WYDOT Field Equipment, as the Central System communicates directly to the RSU. The Central Systems communicate directly to the RSUs using simple network management protocol (SNMP), depositing “Store and Forward” TIMs on the RSU for broadcast.

3.3.1.2. Wyoming V2X Connected Roadways: Central Systems

Wyoming operates a number of subsystems that collectively comprise the Central System supporting V2X Connected Roadways, summarized as follows:

- **Wyoming Traveler Information System (WTI).** The WTI collects data on current conditions and events by calling in to a Wyoming Data Broker Representational State Transfer (REST) service. The Wyoming WTI builds the TIMs using this data and creates additional information regarding which RSUs each TIM should be sent to. The TIMs currently created by the WTI include the following: Spot Weather Impact Warning (SWIW), work zones, incidents, variable speed limits (VSLs), parking availability, chain-up requirements, and blow-over risks for light, high-profile vehicles.
- **Wyoming ODE.** The Wyoming ODE distributes the TIMs to the appropriate RSU as identified by the WTI using SNMP to deposit the TIMs as “Store and Forward” TIMs on the RSU for broadcast.
- **Wyoming CV Manager.** The CV Manager is hosted in WYDOT’s datacenter and provides a portal view of the health of RSUs and allows for various CV data visualizations. CV Manager also supports RSU management and RSU upgrades for firmware. All processed SAE J2735 messages are decoded, converted into processed JSON, and stored in a Mongo database for data analysis.
- **SDX.** The SDX is a component of the Central System and performs multiple roles as follows:
    - The SDX receives TIMs from the ODE and delivers TIMs through the Sirius XM communications to OBUs (as outlined in the Vehicle Systems).
    - The SDX also serves as a data exchange that allows consuming systems to collect the TIMs directly from the SDX, enabling network cellular communication of TIMs.

3.3.1.3. Wyoming V2X Connected Roadways: Vehicle Systems

The vehicles currently performing two-way communications with the Wyoming V2X Connected Roadways are public agency vehicles, specifically snowplows, maintenance supervisor vehicles, and other vehicles operating in the area. In addition, any vehicle passing by Field Equipment may receive the broadcasts and/or may be broadcasting the BSM.

The Vehicle Systems supporting the Wyoming V2X Connected Roadways include the following:

- **OBUs.** WYDOT currently uses Commsignia OBUs connected to Samsung tablets that serve as the HMIs.
    - The OBUs operate C-V2X communications to send and receive messages when in range of RSUs and Sirius XM communications to receive messages statewide.
    - These OBUs generate and broadcast BSMs with the data available from the OBU (i.e., no access to the vehicle bus to extract vehicle generated data).
    - These OBUs also receive, process, and display TIMs generated by the Central System.

- Each Commsignia OBU is enrolled in the ISS SCMS.
- Snowplow vehicles are loaded with identity certificates, and 4 weeks of certificates are stored on the OBU.
- Other WYDOT vehicles are loaded with Pseudonym certificates with 3 years of certificates stored on the OBU.

3.3.1.4. Wyoming V2X Connected Roadways: External Systems

The external systems supporting Wyoming's V2X Connected Roadways include the data sources that are accessed to formulate the content of the TIMs that are delivered to RSUs and broadcast. These include:

- Wyoming Data Broker REST service
- Sirius XM Services

3.3.2. Wyoming Existing C-V2X Systems Schematic

The following schematic (Figure 2) illustrates the existing Wyoming SOI that is related to the CTW Program, as explained above in Section 3.3.1.

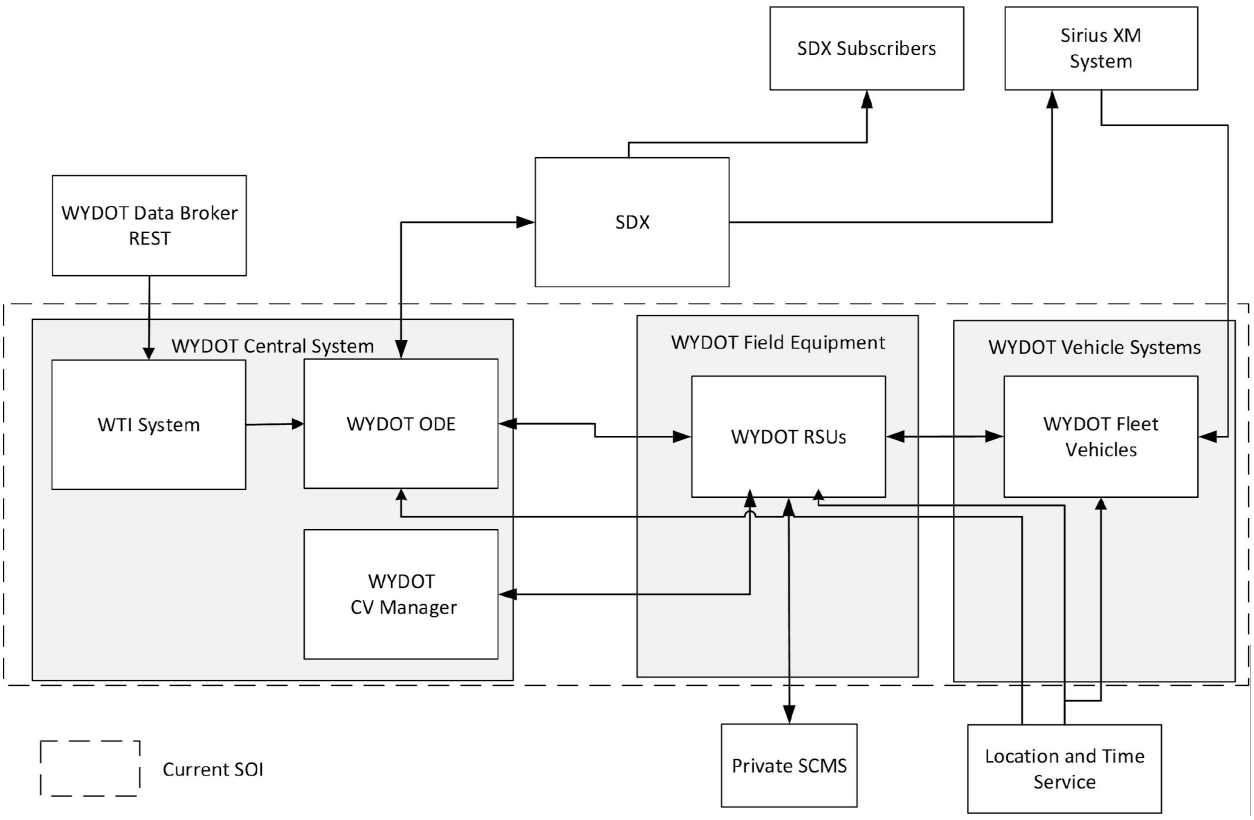

Figure 2. Wyoming Existing System of Interest Physical Architecture
Source: Athey Creek Consultants, February 2025

3.4. Colorado Current Systems

Relevant systems currently operating in Colorado include CIs and V2X Connected Roadways. Details about each are provided in this section.

3.4.1. Colorado Connected Intersections

CDOT currently operates 26 CIs in CDOT Region 1 that utilize C-V2X technologies to communicate with vehicles. These 26 locations are along two corridors: Wadsworth Boulevard and East Arapahoe Road. The primary use of these CIs is currently to support priority for snowplows.

These CIs consist of three subsystems: Field Equipment, Central Systems, and Vehicle Systems. Descriptions of each of these subsystems are included below.

3.4.1.1. CDOT Connected Intersections: Field Equipment

The CDOT CI Field Equipment consists of following:

- **RSUs.** The CDOT RSUs at the intersections receive SRMs broadcast by vehicles, verify the security credentials of the messages, and then pass the request for low-level preemption to the signal controller. Currently, the signal controllers are configured to accept snowplow preemption when requested during winter months and not accept it during non-winter months.
    - The RSUs interface with the signal controller to receive the status of the signal controllers and use this to generate and broadcast SPaT messages.
    - The RSUs store MAP messages created for each intersection and broadcast these messages.
    - The RSUs generate SSMs to acknowledge the receipt of the SRMs and also include in the SSM indicators of whether preemption was granted.
    - All RSUs are configured to forward transmitted and received J2735 messages to a backend ODE hosted in the Google Cloud Platform (GCP). CDOT also supports OTA updates for OBU via Wi-Fi through select RSUs.

3.4.1.2. Colorado Connected Intersections: Central Systems

Two components of the Colorado Central System supporting CIs are as follows:

- **Colorado CV Manager.** The CV Manager is hosted in GCP and provides a portal view of the health of RSUs and allows for various CV data visualizations. The CV Manager also supports RSU management and RSU upgrades for firmware. All processed SAE J2735 messages are decoded, converted into processed JSON, and stored in a database (i.e., MongoDB and GCP BigQuery) for data analysis. The CV Manager has full integration with the CIMMS Conflict Monitor and Conflict Visualizer application programming interface (API) to display CI-associated events.
- **CIMMS.** All Colorado CIs interfaces with CIMMS, enabling CIMMS to access messages that include BSMs, SPaT, and MAP. CIMMS performs tests to identify conflicts and anomalies, as described in Section 3.2.1.

3.4.1.3. Colorado Connected Intersections Vehicle Systems

The vehicles currently performing two-way communications with the Colorado CIs are CDOT Region 1 fleet snowplows. These vehicles are equipped with OBUs to formulate and send the preferential treatment requests. Aspects of the CDOT Vehicle Systems are as follows:

- **OBUs.** CDOT operates ISS SCMS-enrolled Commsignia OBUs that exchange the following messages:
  - CDOT OBUs receive SPaT and MAP messages from the RSU.
  - CDOT OBUs broadcast SRMs that are formulated by the OBU.
  - CDOT OBUs generate and broadcast partially formulated BSMs. The OBUs do not include CAN bus integration, so only a portion of the BSM core data can be populated with actual data. The OBUs are designed for anonymity by rotating the vehicle ID associated with the vehicle.
  - The CDOT OBUs also receive SSMs that indicate the preemption request was received and if preemption is granted.
  - As the OBU progresses and passes through the intersection, SRM cancellations are broadcast to indicate to the RSU to cancel the preemption calls.

3.4.1.4. The Colorado Connected Intersections: External Systems

The traffic signal controller at each CI is an external system.

3.4.2. Colorado V2X Connected Roadways

CDOT has an operational system along IRCs (e.g., V2X Connected Roadways) that collects data from CVs and communicates alerts and warnings to drivers through the use of TIMs delivered to and broadcast by RSUs along the roadside. CDOT currently is testing and piloting these deployments and has approximately 40 CDOT vehicles consisting of maintenance and other test vehicles in the fleet. The active RSUs supporting V2X Connected Roadways include:

- 241 RSUs on I-25
- 172 RSUs on I-70
- 45 RSUs on C-470 in the Denver area
- 12 RSUs on I-225 in the Denver area
- 5 RSUs on I-270 in the Denter area
- 14 RSUs on I-76 northeast of Denver

The following subsections describe aspects of the Field Equipment, Central System, and Vehicle Systems that currently comprise the CDOT V2X Connected Roadways implementations.

3.4.2.1. Colorado V2X Connected Roadways: Field Equipment

The Colorado Field Equipment includes:

- **RSUs.** The RSUs in Colorado are similar to the Wyoming RSUs. The RSUs are connected through fiber communications where available. RSUs located where fiber is not available are connected by cellular modems. The RSUs are secure and broadcast messages with security credentials. A summary of the messages exchanged at the RSUs is as follows:
    - The RSUs receive TIM messages from the Central System and broadcast these messages, typically at a frequency of 1 Hz. The RSUs attach security credentials to the TIMs at the RSU before broadcasting.
    - The RSUs also receive BSMs broadcast by Vehicle Systems and forward those messages to the Central System. The RSUs only retain and forward to Central Systems those BSMs with security credentials.

There are no additional supporting devices as part of the CDOT Field Equipment, as the Central System communicates directly to the RSU using SNMP and depositing "Store and Forward" TIMs on the RSU for broadcast.

3.4.2.2. Colorado V2X Connected Roadways: Central Systems

Colorado operates a number of subsystems that collectively comprises the Central System supporting V2X Connected Roadways, summarized as follows:

- **CDOT's ATMS.** The ATMS, which is a Q-Free product, generates work zone TIMs with supporting information about where they should be distributed.
- **Work Zone Reports.** CDOT is pursuing a pilot approach for generating content for TIM messages, which is to collect data from static forms created for work zones that identify where and when reduced speed advisories are planned for work zones. The content from these forms are aggregated and formed into Work Zone Data Exchange (WZDx)-compliant messages. From these WZDx messages, the Central System formulates TIMs that describe the reduced speed advisories.
- **CDOT ODE.** The ODE distributes the TIMs to the appropriate RSU, using SNMP to deposit the TIMs as "Store and Forward" TIMs on the RSU for broadcast. The TIMs are created by information originating with the CDOT ATMS (see Section 3.4.2.4) and only include work zone TIMs at this time.
- **Colorado CV Manager.** The CV Manager is hosted in GCP and provides a portal view of the health of RSUs and allows for various CV data visualizations. In Colorado, the CV Manager has full integration with the CIMMS Conflict Monitor and Conflict Visualizer API to display CIs and associated events. The CV Manager also supports RSU management and RSU upgrades for firmware.

3.4.2.3. Colorado V2X Connected Roadways: Vehicle Systems

The vehicles currently performing two-way communications with the Colorado V2X Connected Roadways are public agency vehicles that include maintenance and other fleet vehicles. In addition, any vehicle passing by Field Equipment may receive the broadcasts and/or may be broadcasting the BSM.

The Vehicle Systems supporting the CDOT V2X Connected Roadways include the following:

- **OBUs.** The OBUs in Colorado are similar to the WYDOT OBU approach and utilize Commsignia OBUs.
  - The OBUs generate BSMs, apply security credentials, and broadcast the BSMs at 10 Hz.
  - The OBUs receive and process TIMs and display the information through an HMI. Some CDOT staff have opted not to have the HMI activated, but these vehicles still generate and broadcast BSMs.

3.4.2.4. Colorado V2X Connected Roadways: External Systems

The external systems supporting Colorado's V2X Connected Roadways include the data sources that are accessed to formulate the content of the TIMs that are delivered to RSUs and broadcast. These include:

- **CDOT's ATMS (a Q-Free product).** The ATMS generates work zone TIMs with supporting information about where they should be distributed. CDOT does not currently generate additional TIMs.

3.4.3. CDOT Existing C-V2 X Systems Schematic

The following schematic (Figure 3) illustrates the Colorado SOI that is related to the CTW Program, as is explained above in Sections 3.4.1 and 3.4.2.

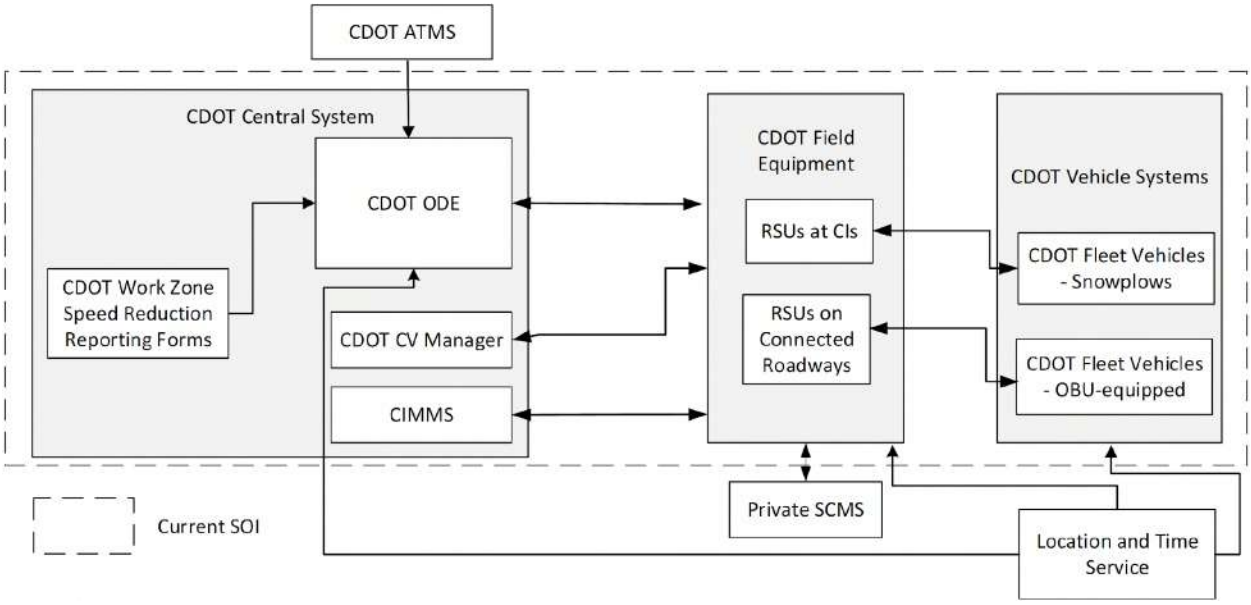

Figure 3. Colorado Existing System of Interest Physical Architecture
Source: Athey Creek Consultants, February 2025

3.5. Relationship to Other Systems

The following are examples of other systems with relationships to the CTW Program that will be considered throughout the systems engineering process.

CIs to Support OEM RLVW Applications. A key benefit that is expected of CIs is that production (and aftermarket) RLVW applications deployed in vehicles will use the CI messages to warn drivers at risk of entering intersections during red lights. There has been a strong message from the OEMs that the data broadcast by CIs needs to be consistent, accurate, and dependable across CIs for the OEMs to move forward with equipping production vehicles with these applications. For these reasons, FHWA has sponsored the CTI effort that has developed a CI Implementation Guide and requirements for CIs that meet the demands of OEMs.

The CTW Program partners are aware of and participate heavily in this effort and will continue to throughout this program. The requirements developed by the CTI effort will form the basis of many requirements in the SyRS document, either by reference or reproducing.

This is an area where CTW members expect close coordination with the other V2X Acceleration Sites as they are all deploying CIs.

Universal Use of TIMs. While the SAE TIM standard has existed for decades, the lack of widespread use of TIMs is such that there is no uniform guidance around the use of TIMs. Encouraging common use of TIMs (e.g., when a specific TIM is used, the structure of the TIM, etc.) will allow OBU manufacturers to implement TIM processing into OBUs and allow common applications to be created. This is an area where the CTW team has been coordinating among members as well as with representatives from University of Arizona and Ohio Department of Transportation (DOT). Also, through the CV PFS, there are broader discussions about the common TIM definitions for work zone TIMs.

Third-Party Traveler Information Systems (TISs). A survey conducted by UTires revealed that “over 60% of Americans use a GPS service at least once a week” and that “83% of respondents said they would get lost without their GPS” (UTires, 2024). The widespread use of third-party traveler information systems represents an outside system to the CTW Program that CTW will interact with and leverage as much as possible. While the number of vehicles equipped with OBUs is still small but growing, CTW Program partners recognize the value of sharing the standardized messages with third-party systems that are commonly used by travelers throughout these states, and the SDX that is a core system of this program already has established relationships to share data and will continue to expand these. Nonetheless, these mapping and navigation systems are often privately operated entities, and while CTW can send messages to them, there is no control over how they are used, which is why the program will continue to engage with them to benefit travelers as much as possible.

4. Justification for and Nature of Changes

In order to align the CTW Program goals with the challenges facing travelers and transportation professionals and ultimately the V2X systems to be deployed in the participating member states, four CTW Program focus areas have been identified:

- Signalized Intersections (SIs)
- Interstates and Rural Corridors (IRCs)
- Vulnerable Road Users (VRUs)
- Interoperability and Compatibility (IC)

The justification for change is rooted in the challenges facing travelers and stakeholders in the CTW participating states. These challenges are defined within the program's four focus areas and are described in detail in the following sections of this ConOps. To address these challenges, several proven and emerging solutions are identified and represent the nature of the changes anticipated for this CTW Program.

4.1. Challenges to be Addressed by the CTW Program

An early step in the systems engineering process is to identify the challenges that are the basis for the changes to be implemented by the proposed system. Identifying these challenges does not imply they are the only challenges facing the end-users, but rather they identify those challenges to be addressed by the proposed system. These challenges will be the basis for identifying the user needs, the objectives, and ultimately the requirements for the new system. The challenges to be addressed by the CTW deployment are summarized below, presented for each of the four CTW Program focus areas as well as general challenges.

4.1.1. Signalized Intersection Challenges

Challenges associated with the SI focus area include:

- **Challenge SI-1:** In Utah, at SIs not operating TSP, transit vehicles experience delays that impact route performance, transit riders, and transit agencies.
- **Challenge SI-2:** In Utah, at SIs not operating emergency vehicle preemption, emergency vehicles approaching the intersections are more likely to encounter conflicts and/or delays.
- **Challenge SI-3:** In Utah, snowplows stopping at red lights interrupt their movement of snow and reduce the efficiency of snow removal operations.
- **Challenge SI-4:** In Utah, at intersections without preemption or priority, idle times of buses and snowplows while waiting at red lights contribute to air quality concerns.

- **Challenge SI-5:** While in-vehicle RLVW applications are expected to reduce serious or fatal crashes, their widespread use is hindered by the unavailability of accurate, reliable, and timely data from the traffic signal controllers being broadcast by the intersections.
- **Challenge SI-6:** Without adequate measures of effectiveness relative to the vehicles receiving signal priority or preemption (e.g., delays or efficiency), agencies are not able to assess the operational impacts of SIs equipped with preferential treatment capability.

4.1.2. Interstates and Rural Corridors Challenges

Challenges associated with the IRC focus area include:

- **Challenge IRC-1:** In all three CTW states, drivers in vehicles encountering localized adverse weather or pavement conditions can experience reduced visibility, traction, and vehicle stability, and these localized conditions can be difficult for drivers to anticipate without advanced warnings.
- **Challenge IRC-2:** In all three CTW states, vehicles entering curves at speeds that are too high for safe navigation can lead to loss of vehicle control or lane departures.
- **Challenge IRC-3:** In all three CTW states, reduced speeds, lane closures, or lane geometry changes due to work zones, incidents, or other events present safety issues for travelers and workers.
- **Challenge IRC-4:** In all three CTW states, delays due to work zones, weather, or incidents cause significant delays, impacting long-haul freight and leisure travelers.
- **Challenge IRC-5:** In all three CTW states, commercial vehicle operators struggle to find truck parking along the routes in and surrounding this area, causing delays for trucks and uncertainty by truckers that they will find parking at the end of their allotted drive time.
- **Challenge IRC-6:** In all three CTW states, drivers commonly use third-party traveler information applications to navigate their route, and these systems do not always have the most current information about roadway conditions or events.
- **Challenge IRC-7:** Without adequate measures of effectiveness (e.g., data collected and alerts/warnings issued) along C-V2X-instrumented V2X Connected Roadways, agencies in CTW states would be unable to assess the impacts to travelers and benefits of systems.

4.1.3. Vulnerable Road Users Challenge

Challenges associated with the VRU focus area include:

- **Challenge VRU-1:** Drivers entering SIs or making right or left turns may not see VRUs and, as a result, an unacceptable number of crashes involving VRUs occur.

4.1.4. Interoperability and Compatibility Challenges

Challenges associated with the IC focus area include:

- **Challenge IC-1:** Without standards-based messages with industry-accepted clarifications of interpretations or optional elements, the interoperable use of data to support in-vehicle alerts

throughout North America will be challenging or not possible. (Background: DOTs have a history of communicating to drivers and travelers through signs, websites, mobile applications, and phone systems, all of which are consumed by humans. Communications to CV applications operating in vehicles or on personal communication devices do not have the benefit of humans interpreting the messages and/or data. For example, if a message is received about an Interstate closure due to winter weather conditions, a human would be able to infer that adjacent county roads would likely be experiencing similar or worse conditions.)

- **Challenge IC-2:** As OBU capabilities evolve such that future devices become more sophisticated and capable of receiving messages and displaying content drivers, lack of uniformity in how OBUs receive and process standardized messages (including TIMs) will be a barrier to uniform application use across North America.
- **Challenge IC-3:** The CTW sites use SCMS certificates to secure RSU and OBU broadcasts but have not yet demonstrated the interoperable use of these certificates by vehicles traveling through multiple states, which is a key aspect to gaining automakers' trust.

4.1.5. General Challenges

Challenges that span across multiple focus areas include:

- **Challenge G-1:** The broadcasts of C-V2X messages for receipt by RSUs and OBUs in close proximity introduce risks of unauthorized systems broadcasting messages that are not trusted.
- **Challenge G-2:** Industry experience with technologies related to C-V2X and VRU detection systems has shown that it is critical to monitor the health of Field Equipment to avoid outages and to ensure accurate, reliable, and timely message creation and broadcasts.
- **Challenge G-3:** Fleet vehicles in all CTW Program states that are equipped with OBUs must periodically top off security certificates and initial approaches involving the 4G cellular modems' require monthly cellular service plans. An alternate approach involving Wi-Fi communications has been demonstrated but is not yet implemented in all vehicles.

4.2. User Needs

4.2.1. User Classes and Other Involved Personnel

The user classes and other involved personnel that will interact with the system of interest for this CTW Program represent key stakeholders involved in the CTW Program. The CTW user classes (i.e., stakeholder groups) are defined in Table 1.

Table 1. CTW User Classes
Source: Athey Creek Consultants, February 2025

User Class	Definition
All CTW States	CDOT, UDOT, WYDOT, and other CTW partner entities that will deploy or benefit from one or more of the proposed CTW systems.
CDOT	A CTW agency in Colorado that will deploy one or more of the proposed CTW systems, with a focus on CIs and Connected Roadways to deliver in-vehicle traveler information.
UDOT	A CTW agency in Utah that will deploy one or more of the proposed CTW systems including CIs, Connected Roadways, and VRU Safety Systems.
WYDOT	A CTW agency in Wyoming that will deploy one or more of the proposed CTW systems, with a focus on Connected Roadways to deliver in-vehicle traveler information.
Public Agencies in Utah that Operate SIs	UDOT and other public agencies (e.g., cities and counties) in Utah that operate SIs that are anticipated to deploy CTW systems at additional SIs.
Public Agencies in Colorado that Operate SIs	CDOT and other public agencies (e.g., cities and counties) in Colorado that operate SIs that are expected to continue to operate throughout the CTW Program.
UTA	A CTW partner agency that operates a limited number of transit vehicles equipped to receive preferential treatment at CIs in Utah. UTA will equip additional transit vehicles with V2X technology to receive preferential treatment through the CTW Program.
TOCs in CTW States	TOCs at CDOT, UDOT, and WYDOT that monitor and manage traffic conditions and will interact with one or more of the proposed CTW systems.
Drivers	Drivers of vehicles that are equipped to receive messages from CTW systems, including drivers of CTW agency fleet vehicles, transit vehicle operators, emergency vehicle operators, snowplow operators, and commercial vehicle operators.

4.2.2. User Needs

To deliver a system that addresses the challenges identified above, the key next step is to identify user needs. Since the CTW Program is being built upon existing C-V2X deployments in each of the three states, many of the user needs were already understood by the CTW team. The approach taken for this effort was as follows:

- Internal CTW workshops were conducted to discuss the end-user needs that drove the development and deployment of the existing C-V2X systems and to discuss where these legacy systems need to be expanded. As a result of these workshops, a long list of needs was identified (131 in total) and is included in Section 9 of this document. These are identified as “Original” user needs (and are assigned identifiers that begin with “orig-“). The original set of needs captured the specific users

related to each need, and these were the basis for the legacy systems that exist in Utah, Colorado, and Wyoming.

- The original user needs were combined and analyzed to develop a set of consolidated needs for the proposed system enhancements and expansions in CTW as well as to define operational policies and constraints that will need to be addressed as part of the proposed system.
- The internal CTW workshops also discussed the needs for new functionalities that do not exist in the legacy systems.

One key emphasis of the CTW Program is on expanding the existing legacy systems. Therefore, many of the user needs described in this section emphasize the expansions of existing functionalities but do not restate the original user needs that led to these.

Through the process of identifying user needs, the CTW team discussed the challenges described in Section 4.1 and identified what CTW Program partners, drivers, and VRUs need from the proposed system. Details of specific needs discussed during CTW Program workshops are captured in Section 9, and the details described in these needs will be carried forward to future stages of the CTW Program. However, the more detailed user needs have been combined and analyzed to develop a set of consolidated needs for the proposed system.

It is important to note that the CTW Program is expanding existing systems with available funding, and in some of the need descriptions only one or two of the CTW states are called out. This is because those needs are not identified as needs to be addressed by all CTW sites as part of the CTW Program – not that the need does not necessarily translate to all sites. This may be because the CTW partner already addresses the challenge or the challenge was not prioritized to be included in the CTW Program.

Each of the consolidated user needs maps to one or more challenges presented in Section 4.1. The challenges represent the rationale for each of the user needs listed in Table 2. Furthermore, this table identifies the CTW user needs and includes the mapping of each user need to the appropriate challenge(s).

Table 2. User Needs for the CTW System Mapped to Challenges
Source: Athey Creek Consultants, February 2025

User Needs	Challenges Proposed to be Addressed by the CTW Program
CTW-1: Need expanded SI preferential treatment. UDOT, UTA, and local agencies in Utah that operate SIs, as well as drivers, need SI preferential treatment to expand to additional intersections and vehicles. *Note: Expansion of SI preferential treatment was not identified as a need for CDOT or WYDOT in the CTW Program.*	• Challenge SI-1: In Utah, at SIs not operating TSP, transit vehicles experience delays that impact route performance, riders, and transit agencies. • Challenge SI-2: In Utah, at SIs not operating emergency vehicle preemption, emergency vehicles approaching the intersections are more likely to encounter conflicts and/or delays. • Challenge SI-3: In Utah, snowplows stopping at red lights interrupt their movement of snow and reduce the efficiency of snow removal operations. • Challenge SI-4: In Utah, at intersections without preemption or priority, idle times of buses and snowplows while waiting at red lights contribute to air quality concerns.

User Needs	Challenges Proposed to be Addressed by the CTW Program
CTW-2: Need additional CIs. To encourage RLVW applications, public agencies in Utah that operate SIs need to expand the number of SIs that operate as CIs that broadcast messages for in-vehicle safety applications. *Note: This need was not identified as a need for CDOT or WYDOT in the CTW Program.*	• Challenge SI-5: While in-vehicle RLVW applications are expected to reduce serious or fatal crashes, their widespread use is hindered by the unavailability of accurate, reliable, and timely data from the traffic signal controllers being broadcast by the intersections.
CTW-3: Need accurate, reliable, and timely data broadcasts at CIs. Public agencies in Utah and Colorado that operate SIs and drivers need their existing CIs or additional CIs added through the CTW Program to deliver accurate, reliable, and timely data. *Note: This need was not identified as a need for WYDOT in the CTW Program.*	• Challenge SI-5: While RLVW applications are expected to reduce serious or fatal crashes, their widespread use is hindered by the unavailability of accurate, reliable, and timely data from the traffic signal controller being broadcast by the intersection.
CTW-4: Need to expand the creation of SWIW messages. All CTW states and drivers need to increase the creation of messages to support SWIW to equipped vehicles (i.e., vehicles equipped with V2X technology).	• Challenge IRC-1: In all three CTW states, drivers in vehicles encountering localized adverse weather or pavement conditions can experience reduced visibility, traction, and vehicle stability, and these localized conditions can be difficult for drivers to anticipate without advanced warnings.
CTW-5: Need to expand the creation of Curve Speed Warning (CSW) messages. All CTW states and drivers need to increase the creation of messages to support CSWs to equipped vehicles at selected locations.	• Challenge IRC-2: In all three CTW states, vehicles entering curves at speeds that are too high for safe navigation can lead to loss of vehicle control or lane departures.

User Needs	Challenges Proposed to be Addressed by the CTW Program
CTW-6: Need to increase the creation of traveler information alerts and situational awareness notifications. All CTW states and drivers need to increase notifications of events and activities such as work zones, incidents, VSLs, high wind warnings, over height warnings, truck parking availability, and road or lane closures to be distributed to equipped vehicles.	• Challenge IRC-3: In all three CTW states, reduced speeds, lane closures, or lane geometry changes due to work zones, incidents, or other events present safety issues for travelers and workers. • Challenge IRC-4: In all three CTW states, delays due to work zones, weather, or incidents cause significant delays, impacting long-haul freight and leisure travelers. • Challenge IRC-5: In all three CTW states, commercial vehicle operators struggle to find truck parking along the routes in and surrounding this area, causing delays for trucks and uncertainty by truckers that they will find parking at the end of their allotted drive time.
CTW-7: Need to continue and expand, as appropriate, the distribution of TIMs to equipped vehicles. All CTW states need to continue to support (and expand as needed) the distribution of warnings, alerts, and situational awareness notifications (i.e., those warnings, alerts, and notifications created by addressing needs CTW-4, CTW-5, and CTW-6).	• Challenge IRC-1: In all three CTW states, drivers in vehicles encountering localized adverse weather or pavement conditions can experience reduced visibility, traction, and vehicle stability, and these localized conditions can be difficult for drivers to anticipate without advanced warnings. • Challenge IRC-2: In all three CTW states, vehicles entering curves at speeds that are too high for safe navigation can lead to loss of vehicle control or lane departures. • Challenge IRC-3: In all three CTW states, delays due to work zones, weather, or incidents cause significant delays, impacting long-haul freight and leisure travelers. • Challenge IRC-4: In all three CTW states, delays due to work zones, weather, or incidents cause significant delays, impacting long-haul freight and leisure travelers. • Challenge IRC-5: In all three CTW states, commercial vehicle operators struggle to find truck parking along the routes in and surrounding this area, causing delays for trucks and uncertainty by truckers that they will find parking at the end of their allotted drive time.
CTW-8: Need to inform third-party traveler information systems. All CTW states need a common mechanism to share alerts and warnings on IRCs with third-party traveler information systems.	• Challenge IRC-6: In all three CTW states, drivers commonly use third-party traveler information systems to navigate their route, and these systems do not always have the most current information about roadway conditions or events.

User Needs	Challenges Proposed to be Addressed by the CTW Program
CTW-9: Need event-sharing between CTW states. TOCs in CTW states need access to timely and accurate event reports affecting key routes in states adjacent to their jurisdiction.	• Challenge IRC-4: In all three CTW states, delays due to work zones, weather, or incidents cause significant delays, impacting long-haul freight and leisure travelers.
CTW-10: Need to expand locations where data is collected from equipped vehicles. UDOT and CDOT need to expand the locations where they receive BSM data from equipped vehicles to supplement information about vehicle movements, weather, and pavement conditions. *Note: Additional coverage of RSUs in Wyoming was not identified as a need for the CTW Program.*	• Challenge IRC-1: In all three CTW states, drivers in vehicles encountering localized adverse weather or pavement conditions can experience reduced visibility, traction, and vehicle stability, and these localized conditions can be difficult for drivers to anticipate without advanced warnings. • Challenge IRC-2: In all three CTW states, vehicles entering curves at speeds that are too high for safe navigation can lead to loss of vehicle control or lane departures.
CTW-11: Need to secure devices and data. All CTW states need to secure the physical devices and messages communicated as part of the proposed CTW system.	• Challenge G-1: The broadcasts of C-V2X messages for receipt by RSUs and OBUs in close proximity introduce risks of unauthorized systems broadcasting messages that are not trusted.
CTW-12: Need to expand the capability to alert drivers to possible conflicts with VRUs. UDOT and drivers need to expand the capability to detect VRUs at SIs and alert drivers as appropriate. *Note: This need was not identified as a need for CDOT or WYDOT in the CTW Program.*	• Challenge VRU-1: Drivers entering SIs or making right or left turns may not see VRUs and, as a result, an unacceptable number of crashes involving VRUs occur.

User Needs	Challenges Proposed to be Addressed by the CTW Program
CTW-13: Need interoperability and consistency in messages delivered. All CTW states and drivers (i.e., system end-users) need systems to be deployed and operated in a consistent, interoperable, and secure manner to ensure trust.	• Challenge IC-1: Without standards-based messages with industry-accepted clarifications of interpretations or optional elements, the interoperable use of data to support in-vehicle alerts throughout North America will be challenging or not possible.
CTW-14: Need to expand the collection, storage, and management of data for analytics to support CTW expansions. All CTW states need the capability to collect, store, and manage data in order to understand the impacts of deployed systems in the CTW Program.	• Challenge SI-6: Without adequate measures of effectiveness relative to the vehicles receiving signal priority or preemption (e.g., delays or efficiency), agencies are not able to assess the operational impacts of SIs equipped with preferential treatment capability. • Challenge IRC-7: Without adequate measures of effectiveness (e.g., data collected, alerts/warnings issued) along C-V2X instrumented V2X Connected Roadways, agencies in CTW states would be unable to assess the impacts to travelers and benefits of systems.
CTW-15: Need to expand the capability to monitor C-V2X devices' health and status to support additional devices. All CTW states need to understand the status of deployed systems at any given time.	• Challenge G-2: Industry experience with technologies related to C-V2X and VRU detection systems has shown that it is critical to monitor the health of Field Equipment to avoid outages and to ensure accurate, reliable, and timely message creation and broadcasts.
CTW-16: Need Interstate interoperability in SCMS certificates. All CTW states need the SCMS certificates broadcast to be interoperable with other states, enabling vehicles to successfully exchange messages with all three sites.	• Challenge IC-3: The CTW sites use SCMS certificates to secure RSU and OBU broadcasts but have not yet demonstrated the interoperable use of these certificates by vehicles traveling through multiple states, which is a key aspect to gaining automakers' trust.

User Needs	Challenges Proposed to be Addressed by the CTW Program
CTW-17: Need to refine and implement SCMS certificate top-off. UDOT needs to refine and implement a non-cellular approach to top off security certificates in fleet vehicles. *Note: This need was not identified as a need for CDOT or WYDOT in the CTW Program.*	• Challenge G-3: Utah fleet vehicles equipped with OBUs must periodically top off security certificates, and the initial approaches involving 4G cellular modems require monthly cellular service plans. An alternate approach involving Wi-Fi communications has been demonstrated but is not yet implemented in all vehicles.
CTW-18. Need to adhere to standards and to documented best practices. All CTW states and system end-users need systems to be deployed and operated using standards and documented best practices for interpreting and applying standards to facilitate interoperability with other states and systems nationally.	• Challenge IC-1: Without standards-based messages with industry-accepted clarifications of interpretations or optional elements, the interoperable use of data to support in-vehicle alerts throughout North America will be challenging or not possible. • Challenge IC-2: As OBU capabilities evolve such that future devices become more sophisticated and capable of additional processing and determining the appropriate display of messages, lack of uniformity in how OBUs receive and process standardized messages (including TIMs) will be a barrier to uniform application use across North America. • Challenge IC-3: The CTW sites use SCMS certificates to secure RSU and OBU broadcasts but have not yet demonstrated the interoperable use of these certificates by vehicles traveling through multiple states, which is a key aspect to gaining automakers' trust.

4.3. Description of Desired Changes

The CTW states hope to improve safety, improve mobility, and fuel costs. To achieve these goals, several new or expanded capabilities, interfaces, and other changes are needed to respond to the previously identified challenges and address the user needs identified previously in Section 4.2.2.

The description of desired changes includes the following categories of changes:

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

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

1. **Expansions of existing capabilities:** The following expansions of existing functions will be performed by the CTW Program:

a. *Expand preferential treatment at CIs.* Expand SI preferential treatment for transit and emergency vehicles and snowplows to additional intersections and vehicles in Utah. Related need: CTW-1.

b. *Expand the number of 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 challenges mentioned in Section 3.1.2 to the extent possible. Related needs: CTW-2, CTW-3.

c. *Expand the number of RSUs broadcasting and receiving messages.* Expand the deployments of RSUs along IRCs to broadcast TIMs and receive BSMs in Utah and Colorado. Related need: CTW-7, CTW-10.

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 the vehicles. Related need: CTW-12.

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. Related need: CTW-15.

f. *Expand security credentialing.* Expand the processes of attaching security credentials to messages exchanged by additional Field Equipment and Vehicle Systems. Related need: CTW-11.

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. Related needs: CTW-13, CTW-16, CTW-18.

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. Related need: CTW-14.

i. *Expand data storage.* Expand data storage processes to support additional RSU data collection sites. Related need: CTW-14.

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. Related needs: CTW-13, CTW-18.

b. *Increase and improve TIM creation*. Expand the capability to create TIM messages (using the consistency approach agreed) that describe SWIW, CSW, alerts, and advisories by increasing the geographic coverage and expanding message content creation in Utah, Wyoming, and Colorado. Related needs: CTW-4, CTW-5, CTW-6.

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. Related need: CTW-9.

d. *Create new TIM exchanges.* Utilize the SDX such that each CTW state sends TIMs and receives TIMs from neighboring states. Related need: CTW-8.

e. *Demonstrate SCMS interoperability.* Conduct demonstrations to understand the extent to which SCMS certificates are interoperable between the CTW states and take steps to achieve interoperability as needed. Related need: CTW-16, CTW-18.

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. Related need: CTW-17.

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. Related needs: CTW-1, CTW-2.

   b. *Maintain additional Field Equipment.* In Colorado and Utah, staff will be responsible for maintaining new Field Equipment added as part of this effort. Related need: CTW-15.

   c. *Maintain additional Vehicle Systems.* In Utah, staff will be responsible for maintaining equipment on fleet vehicles that supports C-V2X connectivity. Related needs: CTW-1, CTW-7, CTW-10.

   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. Related need: CTW-14.

4.4. Alternatives Considered

The proposed system is being developed as part of a national program to accelerate V2X deployments. As such, alternatives that do not involve CV approaches were not considered as part of the ConOps development. 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 in the event that alternative approaches that are more conducive to interoperability surface.

4.5. Priorities Among Changes

All of the desired changes identified above are essential to the CTW effort. Given that each state already has operational systems partially supporting the user needs, the anticipated changes primarily reflect expansion or enhancement, and the extent of these will differ by each state. One essential change that all CTW members must accomplish together is the interoperability and consistency aspects of the messages exchanged. A second top priority is adding the data exchange between CTW Program states.

4.6. Changes Considered and Not Included

Changes that were considered and not included as part of the proposed system include:

- Specifically identifying capabilities to address needs related to work zone workers as VRUs. Workers in work zones are considered VRUs, and populating messages delivered to travelers with indications when workers are present is an approach to reducing risks to workers. The CTW team decided not to include additional functions to detect when workers are present. Nonetheless, worker presence is an active field in the WZDx specification, and if CTW states populate this data and generate TIMs that describe workers' presence, these needs would be partially met.

5. Operational Concepts

The operational concepts outlined in this section define program objectives and provide an overview of the anticipated systems for this CTW Program. The operational concepts described herein include the operational policies and constraints, a description of the proposed system including major components and capabilities, and modes of operation.

5.1. CTW Program Objectives

A series of user needs were identified above in Section 4.2 that represent what the users need the CTW Program to accomplish. This section identifies one or more objectives of the CTW Program for each need identified. The objectives defined in this section will enable evaluation of the system changes accomplished in the CTW Program. By describing a series of use case scenarios that are tied to these objectives, CTW Program partners will be able to envision the operations at successful completion of this program.

Table 3, Table 4, Table 5, Table 6, and Table 7 define the CTW objectives related to each CTW focus area and map each objective to one or more user need.

Table 3. CTW Objectives Related to Signalized Intersections
Source: Athey Creek Consultants, February 2025

CTW Objectives Related to SIs	User Needs that Led to CTW Objectives
Objective SI-1: Reduced snow clearance times - Reduce the time for snowplows to complete their snow clearing along more routes than currently supported. *Note: Reduced time to clear routes includes snowplow vehicle idle time reductions that could reduce fuel costs (a stated V2X Accelerator program goal). However, this analysis is complex (i.e., it must factor in the number of vehicles idling at the other approaches to the intersection). Data is not collected now, nor are their plans to collect it, as it is not expressed as a CTW objective to be measured.*	**CTW-1: Need expanded SI preferential treatment.**

CTW Objectives Related to SIs	User Needs that Led to CTW Objectives
Objective SI-2: Increased transit on-time performance – Improve transit vehicle on-time performance along more transit routes than current. *Note: Increased transit on-time performance implies improved access for underserved communities (a stated V2X Accelerator program goal). However, the data to understand the extent of this impact is not simple or collected today, nor are there plans to collect it. It is not expressed as a CTW objective to be measured.*	**CTW-1: Need expanded SI preferential treatment**.
Objective SI-3: Improved safety and reduced delays for emergency vehicles - Reduce the delays and conflicts with other vehicles that occur when emergency vehicles encounter red signal phases when traveling to active events along more routes than current.	**CTW-1: Need expanded SI preferential treatment**.
Objective SI-4: Increase the number of CIs - Increased the number of CIs to demonstrate to OEMs a commitment to operating systems to support in-vehicle safety applications.	**CTW-2: Need additional CIs.**
Objective SI-5: Improved data quality at CIs – To increase the number of Utah intersections operating accurate, reliable, and timely data that is validated against industry accepted approaches.	**CTW-3: Need accurate, reliable, and timely data broadcasts at CIs.**
Objective SI-6: Implement approach to top off security certificates on fleet vehicles – To refine and implement an approach for topping off security certificates for Utah fleet vehicles.	**CTW-17: Need to refine and implement SCMS certificate top-off.**

Table 4. CTW Objectives Related to Interstates and Rural Corridors
Source: Athey Creek Consultants, February 2025

CTW Objectives Related to Interstates and Rural Corridors	User Needs that Led to CTW Objectives
Objective IRC-1: Increase the creation and delivery of messages to support in-vehicle warnings and situational awareness – Increase the geographic area covered and content included in messages created to support SWIW, CSW, traveler information alerts, and situational awareness messages that will eventually reduce the number of crashes and improve mobility of travel. *Note: While an ultimate objective of CTW is to reduce crashes, the area covered, and number of messages is a surrogate for this objective while the number of equipped vehicles is still statistically low.*	**CTW-4: Need to support SWIW to equipped vehicles.** **CTW-5: Need to support CSW.**
Objective IRC-2: Increase the C-V2X delivery of messages to support in-vehicle warnings and situational awareness - Increase the geographic area covered and messages communicated to communicate traveler information alerts and situational awareness that will eventually increase leisure and commercial travel mobility and safety. *Note: While an ultimate objective of CTW is to improve safety and mobility, the area covered and number of messages is a surrogate for this objective while the number of equipped vehicles is still statistically low.*	**CTW-6: Need increased traveler information alert notifications.** **CTW-7: Need ability to provide situational awareness to commercial vehicle operators.**
Objective IRC-3: Communicate traveler information alerts to Third-Party Traveler Information Systems users – To increase the consistent delivery of information and alerts to Third-Party Traveler Information Systems.	**CTW-8: Need to inform third-party traveler information systems.**
Objective IRC-4: Share event reports between CTW states. Accomplish near real-time sharing between CTW states of active event reports in each state's respective systems.	**CTW-9: Need event sharing between CTW states**.
Objective IRC-5: Increase data collection from vehicles. To expand the number of locations where data from vehicles broadcasting BSMs are captured, and to process and store the additional data.	**CTW-10: Need to expand data collection from equipped vehicles.**

Table 5. CTW Objectives Related to Vulnerable Road Users
Source: Athey Creek Consultants, February 2025

CTW Objectives Related to Vulnerable Road Users	User Needs that Led to CTW Objectives
Objective VRU-1: Demonstrate VRU Detection coupled with driver alerts – To demonstrate the coupling of VRU detection with driver alerts by expanding the number of reference implementations to be a model for widespread deployment at intersections by other IOOs nationwide.	**CTW-12: Need capability to alert drivers to possible conflicts with VRUs.**

Table 6. CTW Objectives Related to Interoperability and Compatibility
Source: Athey Creek Consultants, February 2025

CTW Objectives Related to Interoperability and Compatibility	User Needs that Led to CTW Objectives
Objective IC-1: Consensus on message content and structure – To reach consensus on how SAE standards-based messages are formulated and populated for delivery to C-V2X-equipped vehicles, both within CTW states and additional states.	**CTW-13: Need interoperability and consistency in messages delivered to equipped vehicles.**
Objective IC-2: Integrate message consistency into existing CTW systems – To successfully adapt systems in each CTW state to implement agreed message consistency guidelines.	**CTW-13: Need interoperability and consistency in messages delivered to equipped vehicles.**
Objective IC-3: Inform Industry of agreed message consistency definitions - To outreach and educate manufacturers of C-V2X equipment about the consensus reached and demonstrated success of consistent approaches to standardized messages.	**CTW-13: Need interoperability and consistency in messages delivered to equipped vehicles.**
Objective IC-4: Demonstrate Interstate interoperability of SCMS certificates. To gain trust in multistate interoperability of SCMS certificates by demonstrating vehicles traveling while sending and receiving SCMS certificates with RSUs in the each of the CTW states.	**CTW-16: Need Interstate interoperability in SCMS certificates.**

Table 7. CTW Objectives Related to All Focus Areas
Source: Athey Creek Consultants, February 2025

CTW Objectives Related to All Focus Areas	User Needs that Led to CTW Objectives
Objective G-1: Secure Data – To implement security credentialing for all messages broadcast or received by CTW systems and public agency vehicles.	**CTW-11: Need to secure devices and data.**
Objective G-2: Define and implement data storage plan – For each CTW state to define a new or maintain an existing data storage plan for CV data and implement this plan for data exchanged during the CTW Program. Data is expected to include data collected from BSMs that are broadcast as well as those logged when out of range as well as data describing driver alerts, TIMs distributed, and other activities.	**CTW-14: Need to collect, store, and manage data for analytics.**
Objective G-3: Define and implement device monitoring plan – For each CTW state to define a new or maintain an existing plan for monitoring the C-V2X-related equipment and to implement this plan for previously installed and newly deployed C-V2X equipment.	**CTW-15: Need capability to monitor C-V2X devices health and status**.

The objectives set forth for the CTW Program build upon the challenges as well as the proven and emerging solutions that provide a solid foundation for this program deployment.

5.2. Operational Policies and Constraints

While it is very early in the process to be detailing all operational policies and identifying all constraints, 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 product or services available.

The constraints will either need to be addressed as part of the proposed system or predetermine 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 OEMs. (A solution for this constraint is being developed through the UDOT "Verifying Connected Intersections" project as part of the USDOT SMART Grants program.)
- A nationally accepted, common approach is needed to define how CIs validated to meet CTIC 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 SCMS providers, OBUs, and RLVW applications. (This constraint is met through the "Connected Intersections Guidance Document" developed through the CV PFS.) Constraints resulting from this document include:
    - Requirements for CTW systems supporting CIs are constrained by CTIC 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 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 CTW 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 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 RSUs. No additional data sources or field collection of data are being added through CTW. 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 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 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.
- The C-V2X communication to vehicles over wide areas (i.e., excluding the LTE C-V2X communications) in Wyoming will continue to be performed using Sirius XM radio, 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 Program is initiating the solution to this by facilitating discussions with additional states around common TIMs.)
- CTW data exchanges are constrained to use a nationally available SCMS, which is currently only available through ISS.

5.3. Description of the Proposed System

The CTW proposed system is a System of Systems, with an SOI that includes a Central System, Field Equipment, and Vehicle Systems. UDOT, WYDOT, and CDOT will continue to operate their individual

Central Systems and Field Equipment while also continuing to operate fleet vehicles equipped with C-V2X technologies. WYDOT will also continue to operate fleet vehicles equipped with satellite-enabled V2X communications. In addition to the SOI, external systems will support the CTW SOI (e.g., traffic signal controllers and TOCs).

The data flows between portions of the CTW SOI will be the following:

- Cloud-based between the SOI Central System and both the SDX (identified as an External Central System) and various other external systems as well as between the SOI Field Equipment to various external systems.
- Center to center, center to field, and field to field between the SOI Central System and various external systems as well as between the SOI Central System and the SOI Field Equipment.
- C-V2X between the SOI Field Equipment and SOI Vehicle Systems.
- Satellite in Wyoming between the SOI Vehicle Systems and the external system Sirius XM.

Figure 4 shows the CTW SOI, external systems, and data flows.

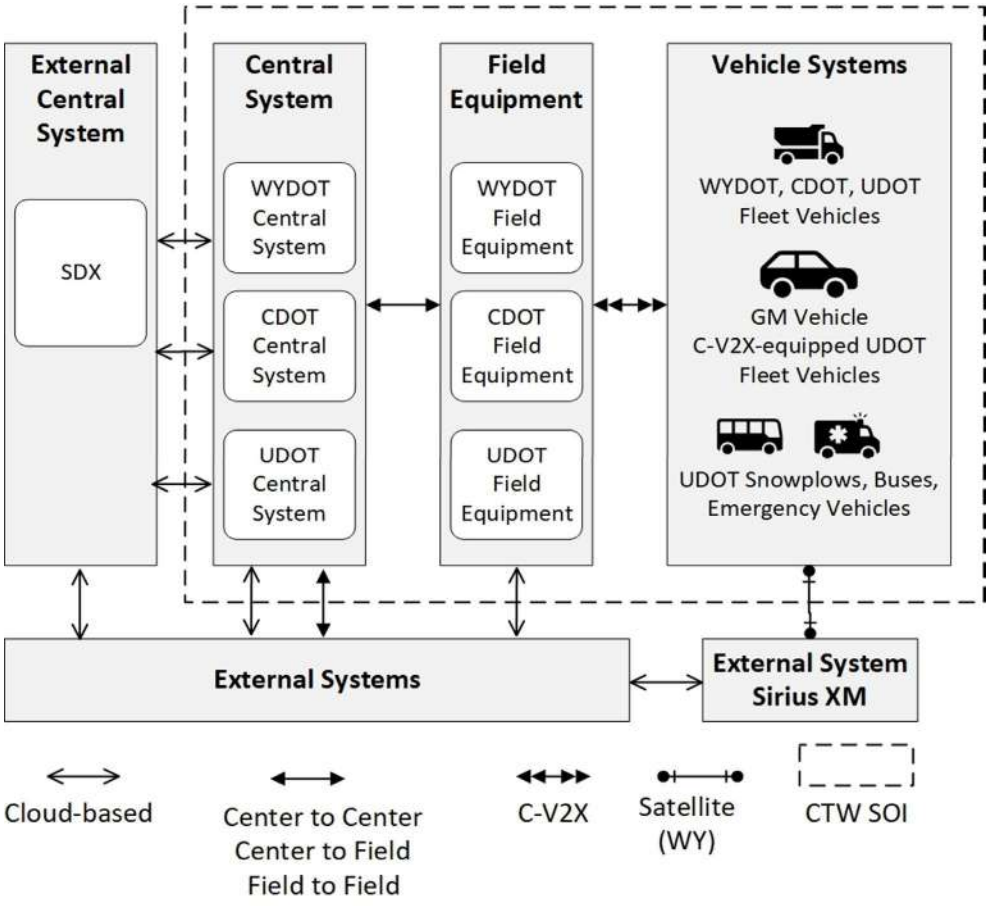

Figure 4. CTW Program System of Interest
Source: Athey Creek Consultants, January 2025

5.3.1. Functions of the Proposed System

The functions of the proposed CTW system are described in terms of the functions that are anticipated to be performed by the following system component types:

- **Central Systems.** Central Systems are systems within the CTW SOI that are operated by each respective CTW partner and are typically housed within DOT facilities or hosting centers and rely upon standard-voltage electricity and Internet communications provided by the facility.
- **Field Equipment.** Field Equipment are roadside devices and equipment (often with built-in or supporting software and systems) that function as part of the CTW SOI and rely on standard-voltage electricity at the site. In rare situations where line-powered electricity is not available, Field Equipment may be powered with solar panels, usually at sites where solar panels already support other ITS equipment.
- **Vehicle Systems.** Vehicle systems include the OBUs and HMIs located in vehicles as well as a collective set of equipment and processing capabilities within vehicles that are equipped with V2X technology as part of the CTW SOI and rely on power provided by the vehicle.
- **External Systems.** External systems are systems that support the CTW SOI and are needed for the overall CTW system functionality. For example, external systems will likely include traffic signal controllers, RWIS, ATMS, or other similar systems.

The expected functions of each system component type are included below. Each function is identified as either:

- **Existing systems used by UDOT, WYDOT, and CDOT, and there is no change to functionality planned.** The only change is typically expanded sites or vehicles using the existing functions.
- **Expanded functionality**. Where appropriate, the functions identify when expanded functionality is being added in CTW.

Central Systems Functions. The functions to be performed by all CTW Central Systems (unless otherwise noted) are expected to be as follows:

1. **Collect BSM Data.** Collect BSMs from Field Equipment (e.g., RSUs) that were received from C-V2X broadcasts of passing CVs. These are existing systems in Utah, Colorado, and Wyoming and there is no change to functionality planned. CTW addition will be: To deploy additional RSUs to collect BSMs from additional locations in Colorado and Utah.
2. **Collect SPaT, MAP, RTCM Messages.** Collect the messages broadcast by Field Equipment at SIs, including SPaT, MAP, and RTCM messages. These are existing systems in Utah and Colorado, and there is no change to functionality planned. CTW addition will be: Expanded intersections in Utah.
3. **Extract Event and Weather Data from BSMs.** Using the BSMs, extract data to be used to generate event reports and TIMs for sharing with other agencies and with drivers. These are existing systems in Utah, Colorado, and Wyoming, and there is no change to functionality planned. CTW addition will be: Processing data from additional RSUs in Colorado and Utah.
4. **Collect Event and Weather Data from External Systems.** Collect event descriptions and/or data from external systems (e.g., RWIS, ATMS) as appropriate and tailor the event descriptions to systems in each state. These are existing systems in Utah, Colorado, and Wyoming, and there is

no change to functionality planned. CTW addition will be: Expanded interfaces in Utah to connect to the UDOT ATMS system.

5. **Generate and Exchange Event Reports.** Generate event reports describing atmospheric and pavement conditions, incidents, work zones, reduced speeds, reduced speed limits, and other events impacting travel. These are existing systems in Utah, Colorado, and Wyoming, and there is no change to functionality planned. CTW addition will be: 1) Expanding reports to address the agreed-upon common event report structure in Utah, Colorado, and Wyoming; 2) processing data from additional RSUs in Colorado and Utah; and 3) implementing a new function to exchange events between CTW states in Colorado, Utah,, and Wyoming.
6. **Collect Messages and Data from VRU Safety Systems.** Collect messages (i.e., SDSMs) and additional data from Field Equipment supporting VRU Safety Systems. These are existing systems used by UDOT, and there is no change to functionality planned. CTW addition will be: Expansion to additional locations.
7. **Collect and Manage Health of System Data.** Collect data and information from field equipment that provides insight into the health and operational status of Field Equipment. This is an existing function of existing systems in Utah, Colorado, and Wyoming, and there is no change to functionality planned. CTW addition will be: Expansion to include collection of data from additional devices added.
8. **Generate TIMs.** Create, update, and expire TIMs that represent the event reports in accordance with agreed content and structure for TIMs as defined by the CTW Program. This is a continuation and expansion of existing functions. CTW addition will be: 1) Modify TIM creation in each CTW states to new agreed TIM approach, 2) expand the event types reported as TIMs, and 3) expand the geographic area covered by TIMs (not bounded by locations of RSUs) in Utah, Colorado, and Wyoming.
9. **Distribute TIMs.** Distribute TIMs to the appropriate Field Equipment (based on location) and to the data exchange. These are existing systems used by UDOT, CDOT, and WYDOT, and there is no change to functionality planned.. CTW addition will be: 1) Expanded TIM distribution to additional RSUs in Utah and Colorado and 2) expanded TIM distribution in Utah and Colorado to include the SDX.
10. **Exchange Data Using Network Communications.** Distribute the TIMs through the SDX to subscribers that are expected to include third party traveler information systems, fleets, and other Central Systems. This is a continuation and expanded use of an existing external system that is used in Wyoming and Colorado. CTW addition will be: 1) Expanded contributions of TIMs to the SDX by Utah and 2) expanded outreach to third party traveler information providers encouraging use of TIMs exchanged through the SDX.
11. **Store Dat**a. Store the data generated by the Central Systems and collected from Vehicle Systems and provide access only to authorized users. These are existing systems used by UDOT, CDOT, and WYDOT, and there is no change to functionality planned. CTW addition will be: Additional data stored from additional RSUs in Utah and Colorado.
12. **Distribute TIMs to Sirius XM (WYDOT only).** Send TIMs to Sirius XM for over-the-air delivery to OBUs connected to in-vehicle Sirius XM antennas. These are existing systems used by WYDOT, and there is no change to functionality or expansion planned.. CTW addition will be: No changes.

13. **Perform SCMS Top off to Fleet Vehicles (UDOT only).** Send SCMS top offs to fleet vehicles using an approach that does not require cellular connection by the vehicle. This is a continuation of existing piloted function. CTW addition will be: Fine-tune approach and expand to additional fleet vehicles in Utah.
14. **Process Data for Performance Management (UDOT and CDOT).** Process data received from field equipment, calculate performance measures, and generate visual dashboards. This is a continuation of existing function. These are existing systems used by UDOT, CDOT, and WYDOT, and there is no change to functionality planned. CTW addition will be: Processing data from additional field equipment deployed in Colorado and Utah.

Field Equipment. The functions to be performed by CTW Field Equipment (unless otherwise noted) are expected to be as follows:

1. **Support Secure Data Exchanges.** Field Equipment shall support secure data exchanges only accepting C-V2X messages with SCMS certificates that are verified by the Field Equipment and only broadcasting messages with SCMS certificates applied**.** This is a continuation of existing function. CTW addition will be: Additional RSUs in Utah and Colorado exchanging data.
2. **Receive BSMs.** Field Equipment will receive BSMs that are broadcast by passing vehicles, check SCMS certificates, and communicate the BSMs to Central Systems. This is a continuation of existing function. CTW addition will be: Additional RSUs in Utah and Colorado collecting additional BSMs.
3. **Receive and Broadcast TIMs.** Field Equipment will receive TIMs generated by Central Systems and broadcast the TIMs with necessary SCMS certificates. This is a continuation of existing function. CTW addition will be: Additional RSU locations in Utah and Colorado.
4. **Receive and Process SRMs (Utah and Colorado only).** Field Equipment will receive SRMs for priority or preemption, confirm SCMS certificates, and communicate with the local traffic signal controller to submit, update, and expire the priority or preemption request, as appropriate. This is a continuation of existing function. CTW addition will be: Additional SIs equipped to support preferential treatment in Utah**.**
5. **Broadcast SSM (Utah and Colorado only).** Field Equipment will generate and broadcast SSMs confirming the receipt of the SRM, and (in Colorado) indication if the preemption request was granted. This is a continuation of existing function. CTW addition will be: Additional intersections equipped in Utah.
6. **Assemble and Broadcast SPaT, MAP, and RTCM Messages.** Field Equipment at SIs will collect data or messages to assemble and broadcast SPaT, MAP and RTCM messages that have been validated in accordance with national standards. This is a continuation of existing function. CTW addition will be: 1) Additional intersections equipped in Utah and 2) testing and validation of field equipment at selected intersections in Colorado and Utah to confirm the validation process is met.
7. **Detect VRUs and Generate SDSMs (Utah only).** Field Equipment at intersections equipped with VRU Safety Systems will detect VRUs in selected intersection crosswalks and create SDSMs describing the location and movement of the VRUs. This is a continuation of existing (pilot locations) function. CTW addition will be: Additional intersections equipped with VRU Safety Systems as pilot demonstrations.

8. **Broadcast SDSMs.** Field Equipment will broadcast SDSMs generated at intersections equipped with VRU warning technologies. This is a continuation of existing (pilot locations) function. CTW addition will be: Additional intersections equipped with VRU Safety Systems in Utah as pilot demonstrations.
9. **Determine Possible VRU-Vehicle Conflicts and Activate Signs (Utah only).** Field Equipment will detect vehicle movements and combine them with VRU locations and movement to determine when predesignated blank-out warning signs should be activated to alert drivers of vehicles equipped or not equipped for C-V2X communications. This is a continuation of existing (pilot locations) function. CTW addition will be: Additional intersections equipped with VRU Safety Systems as pilot demonstrations. Note: Blank-out signs will be visible to drivers with an unobstructed view of the signs. These drivers and vehicles are not considered part of the CTW system.
10. **Communicate Messages and Data to Central Systems.** Field Equipment will send data and messages to Central Systems to support data storage, archive, analytics, and use of the data and/or messages for functions of the Central System. This is a continuation of existing function. CTW addition will be: Central Systems communicating with additional Field Equipment added in Colorado and Utah.

Vehicle Systems. The functions to be performed by **CTW Vehicle Systems** are expected to be as follows:

1. **Generate and Broadcast Partial BSMs.** Vehicle Systems will generate partial BSM messages using data available from the OBU (i.e., no access to the vehicle CAN bus), attach SCMS certificates, and broadcast the BSMs using C-V2X communications. This is a continuation of existing function. CTW addition will be: 1) Additional UDOT fleet vehicles equipped with OBUs, 2) additional transit buses equipped in Utah, and 3) additional UDOT snowplows equipped.
2. **Generate and Broadcast Full BSMs.** The GM vehicle that will be operated as a UDOT fleet vehicle will generate full Part 1 BSM messages, attach SCMS certificates, and broadcast the BSMs using C-V2X communications. This is a new function being added by the CTW Program.
3. **Receive TIMs.** Vehicle Systems will receive TIMs broadcast by the Field Equipment. In Wyoming, Vehicle Systems also receive TIMs broadcast by Sirius XM satellite broadcasts. This is a continuation of existing functions. CTW addition will be: Additional UDOT fleet vehicles equipped with OBUs to receive TIMs and display information through HMIs.
4. **Receive and Process CI messages (Utah and Colorado only).** Vehicle Systems will receive and process the messages broadcast by CIs (i.e., SPaT, MAP, RTCM, and TIMs) to support in-vehicle applications such as RLVW and CIPT. This is a continuation of existing functions. CTW addition will be: 1) Additional equipped vehicles in Utah and 2) addition of a GM-equipped vehicle to the UDOT fleet.
5. **Provide In-Vehicle Application Alerts.** Provides an HMI to the driver to deliver alerts that are received as TIMs, prioritized for the vehicle location and direction of travel. This is a continuation of existing functions. CTW addition will be: 1) Additional UDOT-equipped fleet vehicles and 2) additional GM-equipped vehicle operated as UDOT fleet vehicle.
6. **Generate and Broadcast TSP SRMs (Utah transit vehicles only).** Vehicle Systems in Utah that meet requirements to submit preferential treatment requests will collect data from the vehicle to determine if the vehicle is eligible for TSP. When eligible, the Vehicle System will create and

broadcast SRMs using C-V2X communications, updating and eventually expiring the SRMs. This is a continuation of existing function. CTW addition will be: Additional equipped transit vehicles in Utah.

7. **Generate and Broadcast Vehicle Preemption SRMs (Utah and Colorado only).** Selected Vehicle Systems in Utah and Colorado will either determine when preemption requests are authorized (Utah) or automatically generate SRMs (Colorado) requesting preemption and broadcast the SRMs using C-V2X communications. This is a continuation of existing functions. CTW addition will be: Additional equipped snowplows and emergency vehicles in Utah.
8. **Receive SDSMs and Deliver Alerts (Utah only).** Selected UDOT fleet vehicles will be equipped with OBUs that receive and process SDSMs that are broadcast using C-V2X communications. These OBUs will process the SDSMs and determine if the vehicle trajectory is at risk of conflict with the VRU and deliver HMI alerts to the driver when appropriate. This is a continuation of existing (pilot locations) function. CTW addition will be: Additional UDOT fleet vehicles equipped to participate in pilot demonstrations of VRU Safety Systems.

5.3.2. Interfaces to External Systems

The CTW system includes interfaces to the following external systems to exchange data and information. Where indicated, external interfaces are constraints from existing CTW systems or national systems.

- **ISS SCMS Services.** National system that generates security certificates to manage message security.
  - OBUs will use the ISS SCMS to attach certificates to messages broadcast.
  - RSUs will use the ISS SCMS to attach certificates to messages broadcast.
  - SDX will use the ISS SCMS to attach certificates to messages shared to subscribers.
- **Traffic Signal Controllers**. Local field-to-field communications between CTW Field Equipment and the local traffic signal controllers at equipped intersections in Utah and Colorado:
  - Data exchanges from signal controllers describing current signal status.
  - Data exchanges from RSUs to signal controllers describing signal priority and/or preemption requests.
- **NTRIP RTCM Data Source.** Network connection communications between Field Equipment and NTRIP data sources:
  - RTCM correction messages from NTRIP to CTW Field Equipment in Utah to download RTCM messages.
- **UDOT RWIS Network.** UDOT-operated system that currently provides data used by the UDOT Central System and will continue to be an external system to the CTW system.
- **UDOT ATMS.** UDOT's ATMS is not currently accessed to create traveler information TIMs but will be an external system accessed by CTW.
- **Wyoming Data Broker REST Service**. Center-to-center communications between WYDOT Central Systems and the WY Data Broker REST service to collect information about conditions and events used when generating TIMs.

- **Sirius XM Services**. Center-to-center communications between WYDOT Central Systems and Sirius XM to deliver TIMs for broadcast to Sirius XM receivers then interface between Sirius XM antennas and vehicle OBU HMIs in WYDOT Vehicle Systems.
- **CDOT ATMS.** Center-to-center communications with WYDOT's ATMS for information that is used by the CDOT Central System to generate TIMs.
- **CDOT Work Zone Speed Reduction Reporting Forms.** Center-to-center communications with a data file that contains speed reduction information (or the WZDx messages generated from this file) to gather supplemental information describing the work zones.
- **Vehicles Not Equipped with C-V2X Communications**. Drivers of all vehicles approaching UDOT intersections equipped with VRU Safety Systems may view activated blank-out signs as alerts to VRUs.

5.4. Modes of Operations

This section describes different operational scenarios for the proposed system.

Normal Operations. During normal operations, the full set of functions described in Section 5.3.2 is available. Operations of individual subsystems are being monitored by the service monitor and are functioning normally, with the following clarifications:

- **CIs Validation Status**. The validation of CIs against the CTI-developed requirements enable production vehicle RLVW applications to trust all data from the intersection. Validation status is an additional operational mode that will be reported for each CI. CIs that are not validated are still functional for signal preferential treatment.

Degraded Mode. In a degraded mode, some of the Vehicle Systems, field systems, or Central Systems are not functioning as intended. Depending on the nature of the degradation, different functions and processes are available. For example, OBU malfunctions on vehicles requesting signal preferential treatment would prevent them from requesting or receiving priority or preemption. However the vehicles will operate normally, and the only impact would be temporary lack of preferential treatment. As another example, RSU malfunctions would prevent delivery of TIMs to OBUs. However, information delivery through third-party traveler information systems would still operate.

Cybersecurity incidents are a specific event risk that would lead to systems operating in degraded mode. Two aspects of CTW that position the program and partners well to detect, mitigate, and respond to such events are as follows:

- The CTIC Program is progressing towards a definitive set of CI security requirements that operators of CIs agree to implement.
- The CTW Program is leveraging existing vendor products that have inherent safeguards toward detecting and mitigating cybersecurity incidents.
- The SCMS architecture includes trusted root certificates operated by authorized vendors.

Because the CTW operations will include fleet vehicles at this time, risks of cybersecurity incidents are minimal. However, as the CTW Program advances, the topic of preparing the roles and responsibilities for cybersecurity events will continue to be reviewed and incorporated.

Back-up Mode. In a back-up mode, some of the Central Systems are not functioning as intended. As the Central Systems exist for each partner state, a non-functioning Central System would only impact that state. Due to the risk associated with a malfunctioning Central System, the related use cases for that state would be suspended until functionality is restored.

6. Operational Scenarios

This section provides an overview of major operational scenarios for the proposed CTW system. Collectively, each CTW Program objective is represented within at least one of the six operational scenarios. Each scenario provides a brief description and goal of the objective as well as identified constraints, proposed geographic scope within the CTW effort, actors, preconditions, an example scenario, data needs, and possible issues.

The six operational scenarios are primarily oriented around the objectives related to SIs, IRCs, and VRUs:

1. CI Issuing Preferential Treatment
2. Vehicle Equipped with OEM RLVW Application
3. SWIW
4. Adjacent State Coordination – Wyoming I-80 Road Closed to Commercial Vehicles
5. VSLs
6. Driver Warning of VRU Conflict at an SI

Additionally, the three interoperability and compatibility objectives are each represented within several of these scenarios. Specifically, the goals for these objectives represent activities that are necessary to support the primary objective described in the scenario. The goals for the interoperability and compatibility objectives are:

- **IC-1, Interoperable and Compatible Messages among States:** Demonstrate interoperability and compatibility in messages delivered to CVs within the CTW Program partner states.
- **IC-2, Interoperable and Compatible Messages to Third Parties:** Demonstrate delivery of consistent messages to third-party traveler information systems.
- **IC-3, Collaboration:** Collaborate with other V2X Accelerator program sites to share interoperability and compatibility approaches.

6.1. Connected Intersection Issuing Preferential Treatment

Table 8 describes the first of two operational scenarios for SIs.

Table 8. Operational Scenario for a Connected Intersection Issuing Preferential Treatment
Source: Athey Creek Consultants, February 2025

Description Title	Description Content
Relevant Objectives	SI-1: Reduced snow clearance times SI-2: Increased transit on-time performance SI-3: Improved safety and reduced delays for emergency vehicles
Short Scenario Description	This scenario describes how preferential treatment applications that are deployed at validated CIs will process messages from equipped fleet vehicles to determine whether to modify signal timing at the intersection. The scenario also describes how equipped fleet vehicles process vehicle data and broadcast messages to the CI Field Equipment.
Objective Goal	Reduce travel times of equipped snowplows, transit, and emergency vehicles on corridors with validated CIs with preferential treatment applications and also reduce instances of stop/go conditions for equipped snowplows.
User Needs	CTW-1, CTW-11, CTW-13, CTW-14, CTW-15, CTW-17
Constraints	Preferential treatment in Utah is constrained by the current approach where the decision of whether an SRM is warranted is made by the OBU.
Geographic Scope	SIs operated by UDOT and selected municipal SIs in Utah. (Note: no additional intersections are planned to be equipped in Colorado.)
Actors	CI Field Equipment, CI preferential treatment application, equipped fleet vehicles (e.g., snowplows, transit, and emergency vehicles), Central Systems supporting CIs
Preconditions	• Existing policies for issuing preferential treatment at SIs to equipped fleet vehicles (e.g., transit vehicle authorization to request preferential treatment due to being behind schedule). • Proper lane level positioning accuracy and availability. • Sufficient radio frequency performance. • Clock synchronization within performance targets. • Operational SCMS certificates.

Description Title	Description Content
Example Scenario for Proposed System	1. Equipped fleet vehicle approaches validated CI and receives CI data (e.g., MAP messages) from CI field equipment). 2. Equipped fleet vehicle determines whether an SRM is warranted by processing received CI data and vehicle data (i.e., transit vehicles consider schedule status, snowplows consider whether snow treatment applications are activated, and emergency vehicles determine if lights/sirens are activated), and the equipped fleet vehicle broadcasts an SRM when warranted. 3. CI Field Equipment receives and processes SRMs from approaching fleet vehicles. As part of this processing, the Field Equipment validates the security credentials message that accompanies the SRM. If the SRM security is confirmed, the CI Field Equipment interfaces with the signal controller to submit the priority request, and the signal controller modifies the signal timing as appropriate. The CI Field Equipment broadcasts an SSM (with security credentials attached) to confirm the receipt of an SRM received from the vehicle. 4. CI Field Equipment retains CI data, SRMs, and SSMs for transmission to Central Systems supporting CIs to be archived per IOO data retention policies.
Data Needs	Infrastructure data (e.g., MAP and RTCM messages); vehicle data including vehicle position and status respective to the vehicle type (e.g., transit schedule, lights on, siren on, plow down)
Possible Issues	None identified.

6.2. Vehicle Equipped with Original Equipment Manufacturer Red Light Violation Warning Application

Table 9 describes the second of two operational scenarios for CIs.

Table 9. Operational Scenario for a Connected Intersection Supporting In-Vehicle Safety Applications
Source: Athey Creek Consultants, February 2025

Description Title	Description Content
Relevant Objectives	SI-4: Increase the number of CIs
Short Scenario Description	This scenario describes how messages broadcast from validated CIs may be used to support in-vehicle safety applications (in this scenario, RLVW applications are used but others could be supported). RLVW applications will process messages received from CIs, in conjunction with vehicle data, to determine whether to issue a warning to the driver about the risk of running a red light based on vehicle position and trajectory and signal status.

Description Title	Description Content
Objective Goal	The scenario below describes how in-vehicle safety applications will deliver warnings to drivers. During the CTW Program, the GM vehicle operating as a UDOT fleet vehicle will demonstrate the use of data from intersections to support RLVW application. By demonstrating this, the CTW Program will encourage the production of in-vehicle safety applications through this demonstration and by deploying and validating additional CIs.
User Needs	CTW-2, CTW-3, CTW-11, CTW-13, CTW-14, CTW-15
Constraints	Scenario is constrained by external systems that include traffic signal controllers. Industry testing to date has identified functional limitations of signal controllers that prevent CIs from being fully validated to meet CTI requirements. As signal controllers' primary function is controlling signals, those will remain in operation, and this effort will need to influence the controller manufacturers as much as possible until changes are implemented. This constraint will no longer exist when external systems are enabled with capabilities to meet CTI requirements. A second constraint is the relationship with SCMS Manager that will ultimately enable the process with SCMS providers to issue certificates that indicate intersections are valid to support RLVW applications. This constraint will no longer exist when SCMS Manager issues a policy regarding this process. Additional constraints include: • Clock synchronization within performance targets. • Operational SCMS certificates. A final constraint is that the ultimate approach for continuously monitoring the validated status of CIs (still in development by SCMS Manager) may rely on a large enough sample set of vehicles broadcasting BSMs to continuously monitor the status of the intersections.
Geographic Scope	SIs operated by UDOT; select municipal SIs in Utah and Colorado
Actors	CI Field Equipment, vehicles equipped with RLVW application, Central Systems supporting CIs
Preconditions	Existing RLVW application parameters for the determination of issuing a warning based on vehicle position and speed relative to traffic signal timing. Lane level precision is required for Vehicle Systems to determine the appropriate issuance of RLVW warnings.

Description Title	Description Content
Example Scenario for Proposed System	1. CI Field Equipment continuously broadcasts CI data (i.e., SPaT, MAP, and RTCM messages) and receives BSM data from equipped vehicles in the vicinity. 2. Equipped vehicle continuously broadcasts BSMs as it approaches a validated CI and receives CI data from CI Field Equipment. 3. RLVW application on the equipped vehicle OBU processes CI data received from the IOO and vehicle data that is contained in BSMs (e.g., vehicle position, vehicle heading, vehicle speed, and brake status) to determine whether a warning should be issued to the driver based on established RLVW application parameters that are determined by the OEM. The RLVW application interfaces with the vehicle to provide a warning to the driver, when warranted. (Because most processing responsibility for the RLVW application is on the OBU-equipped vehicle, which is outside the scope of the CTW Program, this step is included for illustrative purposes only.) 4. CI Field Equipment retain CI data and BSMs for transmission to Central Systems supporting CIs to be archived per IOO data retention policies.
Data Needs	Infrastructure data (e.g., SPaT, MAP, and RTCM messages); BSMs (e.g., vehicle data including vehicle position, vehicle heading, vehicle speed, brake status)
Possible Issues	Possible issues include the limitations of some signal controllers and the external influence of SCMS Manager that are noted in the constraints.

6.3. Spot Weather Impact Warning

Table 10 describes the first of three operational scenarios for IRCs. Additionally, this scenario also secondarily pertains to two interoperability and compatibility objectives, as indicated below: IC-2, Interoperable and Compatible Messages to Third Parties and IC-3, Collaboration. Note that this scenario mirrors the provision of messages to drivers for a variety of roadway hazards on IRCs, including curves, incidents, disabled vehicles, and work zones, with slight variations based on the data that is used to generate the TIM. Likewise, this scenario closely mirrors the scenario described below for a VRU objective: VRU-2, Work Zone Worker Presence Reporting and Alerts.

Table 10. Operational Scenario for Spot Weather Impact Warning
Source: Athey Creek Consultants, February 2025

Description Title	Description Content
Relevant Objectives	IRC-1: Increase the creation and delivery of messages to support in-vehicle warnings IRC-3: Communicate traveler information alerts to third-party traveler information system users Objective IC-1: Consensus on message content and structure Objective IC-2: Integrate message consistency into existing CTW systems Objective IC-3: Inform industry of agreed message consistency definitions

Description Title	Description Content
Short Scenario Description	This scenario describes how data about a weather hazard is used to generate and broadcast messages to equipped vehicles in order to provide in-vehicle alerts to drivers about spot weather impacts in the area.
Objective Goal	Increase messaging about hazards to reduce the number of Interstate and rural highway crashes.
User Needs	CTW-4, CTW-5, CTW-8, CTW-10, CTW-11, CTW-13, CTW-14, CTW-15, CTW-16
Constraints	Operational SCMS certificates.
Geographic Scope	Select IRCs in Utah, Colorado, and Wyoming
Actors	Central Systems, Field Equipment, Vehicle Systems
Preconditions	One or more sources of accurate atmospheric weather, road weather, or road condition data; policies for hazard types and threat level of hazards for which to generate and transmit TIMs; lane level precision and low latency communications are not critical.

Description Title	Description Content
Example Scenario for Proposed System	1. Adverse weather conditions occur that result in hazardous roadways (e.g., snow precipitation results in slippery roadways) and are logged as a data element within Central Systems databases. Note that this data element may reflect adverse atmospheric conditions or road weather conditions and be automatically or manually generated (e.g., from road weather information system data or by Traffic Management Center [TMC] operators either during actual events or in simulated events to demonstrate the functionality). 2. Vehicles equipped with capabilities to broadcast BSMs that include parameters that indicate weather impacts (e.g., slippery pavement) are contributors to this scenario as the BSMs are received by RSUs and communicated to Central Systems (e.g., Connected Utah in Utah and the ODE in Wyoming and Colorado) where they are included as data sources to support TIM creation. Only BSMs with valid security credentials are processed by RSUs and used in assembling information. 3. Central Systems in Utah, Wyoming, and Colorado generate TIM messages describing weather impacts using the agreed structure and content for TIMs. 4. Central Systems transmit developed TIMs to: a. RSUs upstream of the described TIM valid area for broadcast to equipped vehicles. b. Third-party traveler information systems for use in navigation applications and other services. 5. Equipped vehicle approaches an RSU upstream of the adverse road weather condition and receives the TIM with security certificates that enable it to determine whether the TIM is valid. 6. Equipped vehicle processes the received TIM and available vehicle data to determine whether to provide information within the TIM to the driver. Information within the TIM is provided to the driver if the TIM is still valid based on the current time and when the vehicle is within the TIM valid area. 7. Drivers traveling throughout the CTW states of Utah, Wyoming, and Colorado will notice consistency in the messages delivered to them through the OBU HMI. Over time, the commercially available OBUs will become more consistent as the agreed message definitions are communicated to OBU manufacturers for them to adapt in-vehicle applications to this consistent approach. 8. Drivers of unequipped vehicles may also view in-vehicle information about the adverse road weather condition if they are using a third-party application that interfaces with the Central System to receive TIMs. 9. When the adverse road weather condition changes or is no longer present, data within the Central Systems is updated to reflect this change and the TIM is updated accordingly. If the adverse road weather condition is no longer present, the TIM is modified to remove information about the condition, and the updated TIM is transmitted to RSUs upstream of the described TIM valid area and third-party providers. As such, drivers approaching the area in equipped vehicles or using third-party traveler information systems will no longer receive a message about the adverse road weather condition. 10. Central Systems retain the atmospheric weather, road weather, or road condition data that was used as a basis for generating TIMs, as well as broadcast TIMs, to be archived per IOO data retention policies.

Description Title	Description Content
Data Needs	Atmospheric weather, road weather, or road condition data corresponding to specified locations, corridors, or areas
Possible Issues	Greater distances between the RSU and adverse weather area risk the broadcast of messages regarding conditions that are no longer accurate. Road condition data may not be updated in a timely manner.

6.4. Adjacent State Coordination – Wyoming I-80 Road Closed to Commercial Vehicles

Table 11 describes the second of three operational scenarios for IRCs. Additionally, this scenario secondarily pertains to three interoperability and compatibility objectives, as indicated below.

Table 11. Operational Scenario for Adjacent State Coordination – Wyoming I-80 Road Closed to Commercial Vehicles
Source: Athey Creek Consultants, February 2025

Description Title	Description Content
Relevant Objectives	Objective IRC-4: Share event reports between CTW states.
Short Scenario Description	This scenario describes how an agency can receive and process information about road conditions, specifically a road closure, in an adjacent state to generate and broadcast messages to drivers in a timely manner for them to prepare and make alternate travel plans, as needed.
Objective Goal	Reduce delays and travel disruptions because of planned or unplanned events by providing upstream information where leisure and commercial travelers have options to alter the time or route of travel.
User Needs	CTW-6, CTW-7, CTW-8, CTW-9, CTW-10, CTW-11, CTW-13, CTW-14, CTW-15, CTW-16
Constraints	Existing data sources are a constraint to this scenario as no additional data sources (i.e., beyond the additional RSUs in Colorado and Utah that will receive BSMs) are being added through the CTW Program, although Utah will add the connection to the UDOT ATMS for event reports.
Geographic Scope	Select IRCs in Utah, Colorado, and Wyoming
Actors	Central Systems, Field Equipment, Vehicle Systems
Preconditions	Existing policies for disseminating information about road closures in adjacent states via RSUs, traveler information websites, social media, and dynamic message signs will inform when and where TIMs are broadcast. Existing agreements will allow for seamless TIM and data exchange between adjacent states, including agreements describing how security certificates for the TIMs exchanged between states are handled. Operational SCMS certificates are also a precondition.

Description Title	Description Content
Example Scenario for Proposed System	1. Central Systems receive event report messages from an adjacent state about a road closure on a corridor that could affect drivers passing through to enter that adjacent state. When an event report message is received about a road closure in an adjacent state on a corridor that would impact travelers, Central Systems generate a TIM that describes the road closure in the adjacent state and a valid region in the jurisdiction of the system that received the event report message. 2. Central Systems transmit developed TIMs to: a. RSUs upstream of the described TIM valid area for broadcast (with applied SCMS certificates) to equipped vehicles. b. Third-party traveler information systems for use in navigation applications and other services. 3. Equipped vehicle, specifically CMV, traveling in the direction of the adjacent state and road closure approaches an RSU upstream of the roadway segment with the road closure and receives the TIM. Note that the equipped vehicle may have a destination and route that is not impacted by the road closure, but would receive the TIM regardless. 4. Equipped vehicle processes the received TIM and available vehicle data to determine whether to provide information within the TIM to the driver. Information within the TIM is provided to the driver if the TIM is still valid based on the current time and when the vehicle is within the TIM valid area. Drivers of unequipped vehicles may also view in-vehicle information about the road closure in the adjacent state if they are using a third-party application that interfaces with the Central System to receive TIMs. Note that the driver may still receive the in-vehicle notification even if their route and destination is otherwise not impacted by the road closure. 5. When the road closure is no longer present, data within the Central Systems is updated to reflect this change and the event message originally shared is updated accordingly to remove information about the road closure. This enables the neighboring states to update the TIMs that were created based on the event report. As such, drivers traveling toward the road closure in equipped vehicles or using third-party applications will no longer receive a message about the road closure. 6. Central Systems retain event report messages received from adjacent states that were used as the basis for generating TIMs, as well as broadcast TIMs, to be archived per IOO data retention policies.
Data Needs	Event report messages from an adjacent state that describes the location of a road closure and valid time for the message
Possible Issues	Depending on how far upstream the TIM is broadcast, the closed road could be reopened by the time a driver receiving the notification would reach that location. Drivers will require alternate sources to understand when a road is reopened.

6.5. Variable Speed Limits

Table 12 describes the third of three operational scenarios for IRC. Additionally, this scenario also secondarily pertains to an interoperability and compatibility objective: IC-3, Collaboration. Note that this scenario may occur simultaneously with the scenario described above for SWIW, such that two separate TIMs may be generated for the same roadway segments to describe the reduced speed posted on VSL signing as well as the weather condition that warrants the reduced speed.

Table 12. Operational Scenario for Variable Speed Limits
Source: Athey Creek Consultants, February 2025

Description Title	Description Content
Relevant Objectives	Objective IRC-2: Increase the creation and delivery of messages to support traveler information alerts and situational awareness
Short Scenario Description	This scenario describes how data systems that support the issuance of VSLs through displays on VSL signs are leveraged to generate TIMs for broadcast to equipped vehicles to provide drivers with supplemental in-vehicle messages (i.e., the in-vehicle delivery of VSLs will only accompany VSL systems with roadway signs that are external systems).
Objective Goal	Reduce speeds when appropriate using VSL signs and messages to support traffic harmonization in which speed variance along key corridors (i.e., applied to all vehicles in all lanes for specific roadway segments) is reduced during adverse weather and other events.
User Needs	CTW-6, CTW-8, CTW-11, CTW-13, CTW-14, CTW-15
Constraints	TIMs describing VSLs can only be broadcast on corridor segments that are equipped with VSL signing (i.e., V2X support of VSLs cannot function without an existing VSL control system and roadway signs).
Geographic Scope	Select IRCs in Utah, Colorado, and Wyoming
Actors	Central Systems, equipped vehicles
Preconditions	Existing policies for posting VSLs on signing will apply to in-vehicle messaging. TIMs will only be generated when a reduced speed limit is posted on VSL signing. Operational SCMS certificates are also a precondition.

Description Title	Description Content
Example Scenario for Proposed System	1. Central Systems access data about speed limits that are posted on VSL signing. When a reduced speed limit is posted on VSL signing, Central Systems generate one or more TIMs that describe the speed limit posted on VSL signing and the applicable roadway segment start and end location. Note that successive roadway segments along an equipped VSL corridor may have different posted speed limits (e.g., to incrementally step down from the maximum posted speed limit of 70 mph to 55 mph to 40 mph). 2. Central Systems transmit developed TIMs to: a. RSUs upstream of the described TIM valid area for broadcast (with applied security certificates) to equipped vehicles. b. Third-Party Traveler Information Application for use in navigation applications and other services. 3. Equipped vehicle approaches an RSU upstream of the roadway segment with a reduced posted speed limit on VSL signing and receives the TIM with valid security certificates. 4. Equipped vehicle processes the received TIM and available vehicle data to determine whether to provide information within the TIM to the driver. Information within the TIM is provided to the driver if the TIM is still valid based on the current time and when the vehicle is within the TIM valid area. Drivers of unequipped vehicles may also view in-vehicle information about the reduced posted speed limit on VSL signs if they are using a Third-Party Traveler Information Application that interfaces with the Central System to receive TIMs. 5. When the reduced posted speed limit on VSL signing changes or is no longer present, data within the Central Systems is updated to reflect this change, and the TIM is updated accordingly. If the reduced posted speed limit is removed completely to revert the roadway segment to the maximum posted speed limit, the TIM is modified to remove information about a reduced posted speed limit on VSL signing and the TIM is transmitted to RSUs upstream of the described TIM valid area and third-party providers. As such, drivers approaching the roadway segment with VSL signing in equipped vehicles or using third-party applications will no longer receive a message about a reduced posted speed limit. Central Systems retain VSL signing data and TIMs to be archived per IOO data retention policies.
Data Needs	Posted speed limit on VSL signing for a given corridor segment and respective location for each given VSL segment
Possible Issues	None identified.

6.6. Driver Warning of Vulnerable Road User Conflict at a Signalized Intersection

Table 13 describes an operational scenarios for VRUs.

Table 13. Operational Scenario for Driver Warning of Vulnerable Road User Conflict at a Signalized Intersection

Source: Athey Creek Consultants, February 2025

Description Title	Description Content
Relevant Objectives	VRU-1: Demonstrate VRU detection coupled with driver alerts
Short Scenario Description	This scenario describes how equipment deployed at SIs is used to detect VRU presence in crosswalks and inform drivers about their potential conflict with VRUs via both roadside infrastructure and in-vehicle messaging. In-vehicle messaging to the driver will only be provided if it is determined that a vehicle is on a trajectory to conflict with the VRU. Similarly, roadside infrastructure will only activate if conditions suggest that one or more vehicle-VRU conflicts will exist.
Objective Goal	Demonstrate the coupling of VRU detection with CV communications to assemble information and disseminate it using in-band communications and visual displays through blank-out signs as a reference implementation to be a model for widespread deployment at intersections and key road crossings by other IOOs nationwide. Alerting drivers to conflicts with VRUs in crosswalks will be the primary goal.
User Needs	CTW-11, CTW-12, CTW-13, CTW-14, CTW-15
Constraints	None identified.
Geographic Scope	Select SIs operated by UDOT
Actors	CI Field Equipment, VRU detection systems, digital warning signs, equipped vehicles, Central Systems
Preconditions	Demonstrated accuracy and effectiveness of LiDAR in determining vehicle and VRU trajectories to identify conflicts. Operational SCMS certificates are also a precondition.

Description Title	Description Content
Example Scenario for Proposed System	1. A VRU (e.g., pedestrian, bicyclist, or micromobility user) enters a crosswalk from the adjacent sidewalk pedestrian landing area at an SI. 2. Deployed VRU detection Field Equipment identifies the presence of the VRU and processes the data to generate SDSMs that describe the VRU location, direction of travel, speed, and trajectory. 3. The SDSMs are communicated to the RSU at the intersection. The RSU applies security certificates and broadcasts the SDSMs. 4. The VRU detection Field Equipment also detects the location and movement of vehicles in selected zones of interest (e.g., right-turn lanes). 5. Vehicle Systems in C-V2X-equipped vehicles that operate VRU applications receive and validate the security of the SDSMs and, with information about the vehicle position and trajectory, determine whether to warn the driver of a possible conflict with the VRU. Warnings are issued through the HMI. When the OBU receives updated SDSMs and/or the vehicle trajectory changes such that there is no longer a possible conflict, the HMI warnings will turn off. 6. The VRU detection Field Equipment processes the SDSMs together with the location and movement of vehicles in selected zones of interest to determine if blank-out signs should be activated to warn drivers who do not have C-V2X-equipped OBUs and HMIs. Signs are activated, as appropriate, to warn drivers only when conflicts are determined. 7. When VRUs and vehicles detected in the zones are no longer on conflicting paths, the blank-out signs will deactivate. 8. VRU detection systems retain VRU detection data for transmission to Central Systems to be archived per IOO data retention policies.
Lane Data Needs	Detected VRU presence with supporting data to create the SDSMs.
Possible Issues	Detection of objects that are either moving parallel to the flow of traffic, not a VRU, or not a possible conflict with vehicles; failure to detect when the VRU has left the crosswalk and continuing to warn that a VRU is present.

7. Summary of Impacts

The impacts of the CTW Program summarized in this section are described in terms of anticipated operational impacts, organizational impacts, and impacts from activities during the development of the CTW Program.

7.1. Operational Impacts

The CTW Program will have a direct impact on the operations of the member states. These impacts include:

- Changes to data management practices within each state to account for the data created by the CTW subsystems from an operational and performance evaluation standpoint.
- Changes to asset management and field maintenance practices to support the maintenance of additional infrastructure added in Utah and Colorado.
- Impacts to winter maintenance activities in Utah to reflect the increased number of intersections supporting snowplow signal preemption and increased maintenance and operations of Vehicle Systems to generate and broadcast preferential treatment requests.
- Impacts to the transit operations activities in Utah to reflect the increased number of intersections supporting TSP and increased maintenance and operations of Vehicle Systems to generate and broadcast preferential treatment requests.

Relationships with third-party traveler information applications are expected to change as the CTW partner agencies present the unified approach to compatible data exchanges from these three states as well as additional V2X Accelerator program sites and CV PFS states.

7.2. Organizational Impacts

The proposed CTW expansions and implementations will also impact the organization and structure of responsibilities across the three states. These impacts include:

- Modification of responsibilities of operators at the TMCs that may be needed to support the transition to and operation of CTW systems that generate TIMs that meet interoperability and compatibility agreements.
- No addition or elimination of job positions are expected as part of the CTW system implementation.
- The development phase is not expected to include training for TMC operators and maintenance staff.
- New systems maintenance and development due to the proposed system expansions in Utah and Colorado will fall on the GIS/Intelligent Transportation System (ITS) staff at UDOT and CDOT.

- New RSU locations will increase workload of telecommunications staff and costs attributable to these systems.
- Dedicated staff resources may be needed to support system monitoring, performance measurement, and evaluation support during the Phase 2 operations phase of this effort.

7.3. Impacts During Development

The development tasks for the proposed system involves the system design, testing, and verification of deployments. Through the activities in Phase 1, additional impacts during the development such as outreach to cities and counties operating SIs, performance management, and collaboration with neighboring states will be discussed and documented.

8. Analysis of Proposed System

The analysis of the proposed system will focus on measuring the extent to which the objectives are met, whether the desired capabilities are accomplished, and user feedback. This section summarizes a preliminary analysis approach of the proposed system and addresses the expected benefits, disadvantages and limitations, and alternatives and trade-offs considered. The information provided below will form the basis for a more detailed description of quantitative and qualitative assessments that will be documented in the Performance Measurement and Evaluation Support Plan within the Phase 1 planning activities.

8.1. Summary of Improvements

The following potential improvements are typically considered for CV technologies:

- Improvements in safety, mobility, and public agency efficiency.
- Reduced fuel costs.

The proposed system described in Section 5.3 focuses heavily on improvements to mobility, agency efficiency, and safety. Reductions in fuel costs are expected to result from the improved efficiency of transit vehicles and snowplows; however, these are expected to be minimal, and are likely not measurable.

From the original CTW proposal, a number of proposed concepts were defined. These concepts are captured in the capabilities defined for CTW systems and subsystems. Table 14 identifies (at a summary level) the proposed concepts and the corresponding potential benefits to be measured.

Table 14. Proposed System Concept Elements and Benefits
Source: Athey Creek Consultants, February 2025

Proposed Concepts	Expected Benefits	Category
CIs • RLVW Alerts • CIPT	• Improved safety at intersections for vehicles equipped with RLVW applications. • Increased mobility of transit riders. • Increased mobility of all drivers following winter storms. • Reductions in time to respond to emergencies. • Increased safety for emergency response vehicles. • Reduced fuel costs.	Public agency efficiency, Mobility, Safety

Proposed Concepts	Expected Benefits	Category
V2X Connected Roadways • Hazard Alerts • Traveler Alerts • Work Zone Alerts	• Improved safety along IRCs. • Better informed drivers about current conditions along their path of travel. • Improved safety and awareness of drivers in and approaching work zones. • Improved safety of workers in work zones. • Increased knowledge of roadway conditions by TMC staff. • Reduced fuel costs.	Mobility, Safety
V2X VRU Safety Systems • VRU and vehicle detection • Delivery of warnings	• Improved safety for VRUs using intersection crossings. • Improved awareness of drivers approaching intersections of the presence of VRUs.	Safety

8.2. Disadvantages and Limitations

The CTW team is acknowledging the following challenges of the proposed system and is considering ways to measure them during the Phase 2 operational demonstration:

- **SI Limitations.** The proposed CIs will have limitations based on traffic signal controllers' capabilities. As external systems with multiple customers, the CTW team will continue to request action from controller manufacturers. Below are two examples of how limitations of external systems impact CTW activities:
  - **Preferential Treatment.** User needs have been identified that the systems record when preferential treatment was granted by the signal controller. However, current signal controllers in Utah do not enable this functionality. This will be documented, and feedback will be provided to the signal controller manufacturer requesting this added functionality.
  - **SPaT Message Generation.** In testing of signal controller output coupled with the creation and broadcast of SPaT messages in conformance with CTI requirements (conducted through external related projects), a number of issues with signal controller output have been identified that create situations where accurate complete SPaT messages are not possible. Interaction is occurring with signal controller manufacturers to reach a solution, but no commitment of a timeline has been agreed upon.
- **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. These benefits will be limited by the number of RLVW applications deployed to vehicles. However, 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 V2X VRU Safety Systems at intersections holds great promise to reduce vehicle and VRU collisions, there is also the potential of information overload to drivers. Monitoring vehicle movements will help evaluate the impacts that the

system has on driver behavior, and this will be a critical surrogate measure because it is impossible to accurately estimate the number of collisions avoided.

- **Crash Prevention Along IRCs.** 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 during development of the Performance Measurement and Evaluation Support Plan.
- **Information Overload.** System capabilities are limited by how much information can realistically be given to drivers before too much information adversely impacts their response to that information. A multitude of possible information 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 Performance Measurement and Evaluation Support Plan.
- **Technology Penetration.** The Phase 2 operational demonstration testing 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 CTW Program 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.
- **Will the Information Shared be Used?** The proposed system will provide information not available today, and a compatible approach across the three states to sharing information to travelers directly and indirectly to travelers through third-party traveler information applications. However, the extent to which this information will be used by travelers is unknown, nor how the third-party traveler information applications will use the information. This will be a focus of the performance measurement activities.
- **Impacts of Improper or Inaccurate Information Disseminated.** The CTW Program performance measure assessment and evaluation should attempt to measure the impact of improper or inaccurate information provided by the system or vehicles. The notifications will be logged and available to those evaluating the system. However, a challenge will be knowing the “truth” to determine if the information disseminated was inaccurate. The evaluation activities may be limited in this regard.
- **Crash Analyses.** Typically, analyzing crash statics requires multiple years of data to result in statistically valid results because of the variability of crash frequencies from year to year. This will be a challenge during the Phase 2 demonstration as well. Early crash data trends will be presented, if available. Additionally, surrogate measures will be developed that will be indicators of safety improvements as part of the performance measurement planning.

8.3. Alternatives and Trade-offs Considered

The proposed system is being developed as part of the FHWA-sponsored V2X Accelerator program activity. As such, alternatives that did not involve V2I connections were not considered as part of the ConOps. In terms of applications, expanding existing and proven applications improving safety, mobility, and agency operational efficiency were the primary focus of the system. The additional focus was on VRU safety, as this was being researched and piloted in Utah.

9. Original User Classes and User Needs for Legacy Systems

This section contains a list of the original user classes and user needs for the CTW system that were identified and developed through a series of workshops during initial stakeholder engagement activities. These detailed original user classes and user needs describe the stakeholders and needs that drove the development of the legacy systems that are being expanded to new locations in each of the CTW states as part of the CTW Program. As the systems engineering process progressed, these original user needs were combined and analyzed to develop a set of consolidated needs for the proposed system enhancements and expansions in CTW as well as to define operational policies and constraints that will need to be addressed as part of the proposed system. These original user needs will also be used to help derive system requirements.

The original user classes (i.e., stakeholder groups) are defined in Table 15.

Table 15. Original User Classes
Source: Athey Creek Consultants, February 2025

User Class	Definition
Transit Vehicle Operators	Drivers of transit vehicles (i.e., buses) that are owned and operated by public transit agencies.
Emergency Vehicle and Snowplow Operators	Drivers of vehicles that provide emergency services such as police, fire, and emergency medical services (e.g., ambulances). **Snowplow Operators** are drivers of state DOT-operated snowplows.
Commercial Vehicle Operators	Drivers of commercial vehicles such as heavy trucks, delivery vehicles, and other for-hire vehicles. Commercial vehicle operators include both independent operators and operators of large commercial fleet vehicles.
All Drivers	Drivers of privately-owned passenger vehicles, drivers of agency fleet vehicles (regardless of type of vehicle), transit vehicle operators, emergency vehicle operators, snowplow operators, commercial vehicle operators, and drivers of any other type of vehicle.
Agencies Responsible for SIs	Public agencies that own and/or operate traffic signals for intersections within their designated areas or jurisdictions.
Agency Performance Management	A public agency (e.g., State DOT, transit agency) function that is responsible for assessing the performance of transportation agency functions, operations, and systems.

User Class	Definition
OEM and Aftermarket Providers of Vehicle Applications	Providers of vehicle-based applications that collect data from a variety of sources, integrate the data, and disseminate information to motorists. These providers include OEMs (e.g., automobile manufacturers) that install applications directly into production vehicles and private sector entities that produce “aftermarket” applications that are installed in vehicles after the vehicle is manufactured.
Security Credential Management System (SCMS) Providers	Service-based entities that provide security certificate services that securely manage messages from CVs.
Third-Party Traveler Information Applications	Vehicle-based applications or phone-based applications, owned and operated by private sector entities, that collect data from a variety of sources, integrate the data, and disseminate information to motorists.
Adjacent State DOT Systems	Systems such as TMC, condition reporting, or TISs operated in adjacent or nearby states that will both be recipients of information from CTW member states and contributors of information. The data exchanges between these centers will ultimately be used by UDOT, WYDOT, and CDOT to formulate their TIMs that are disseminated.
TMC and Traveler Information Staff	**Staff** that provide the public with information about road conditions including weather-related impacts and traffic congestion. TMC staff also monitor road conditions and implement actions to mitigate impacts resulting from traffic incidents and road weather events.
TMC Weather Service Providers	Providers that collect and disseminate weather information and services to transportation agencies for use in TMC operations.
Highway Incident Responders	DOT or law enforcement staff who respond to traffic incidents to assist crash victims, conduct traffic control, manage incident scenes, clear debris, and gather post-incident information.
Traffic Enforcers	Law enforcement staff who are responsible for enforcing traffic laws, including but not limited to speed limits.
DOT Maintenance Dispatchers and Responders	**Staff** that assign agency fleet vehicles and respond to maintenance needs or incident-related situations that occur on agency-operated roads.
Intelligent Transportation Systems (ITS) Device Maintenance Staff	**Staff** responsible for maintaining ITS field devices and systems, including monitoring the functionality and health of devices and systems, installing and calibrating field components or systems, and making repairs.
VRUs Crossing Intersections	Pedestrians, cyclists, people with disabilities or reduced mobility, and users of other types of transport devices such as scooters or skateboards.
VRUs in Work Zones	Highway workers or other road workers on foot in a work zone.
Other States (beyond CTW States)	State and local transportation agencies around the country (beyond Utah, Colorado, and Wyoming) that can benefit from approaches taken, interpretation of national standards, and lessons learned from this CTW project.

User Class	Definition
OBU and In-Vehicle Application Developers	Manufacturers of OBUs and in-vehicle applications who build hardware and software to accept and utilize TIM messages.
CTW Partners	Public and private sector entities on the CTW project team: UDOT, WYDOT, CCDOT, CCD, UTA, Salt Lake City, and GM.

See Table 16 (SIs), Table 17 (IRCs), Table 18 (VRUs), and Table 19 (IC) for original user needs for the CTW system.

Table 16. Original User Needs for Signalized Intersections
Source: Athey Creek Consultants, February 2025

Identifier	Original User Need Title	Original User Need
Orig-1	Determine whether TSP request conditions are met	**Transit Vehicle Operators** need capabilities that automatically determine whether the TSP request conditions are satisfied to maintain bus schedules by extending green interval times or shortening red interval times. (Request conditions might include: When are they allowed? More than 10 passengers on board? And other parameters.)
Orig-2	Generate and send TSP requests for intersections	**Transit Vehicle Operators** need capabilities that generate and send TSP requests for the specific intersection approach that the vehicle is traveling.
Orig-3	Generate and send uniform TSP requests	**Transit Vehicle Operators** need capabilities that generate and send TSP requests in a uniform way for all intersections the vehicle travels in their daily routines.
Orig-4	Send and receive confirmation messages	**Transit Vehicle Operators** need CIs to send and transit vehicles to receive messages confirming whether the request was accepted or denied.
Orig-5	Automatically determine when preemption is needed	**Emergency Vehicle and Snowplow Operators** need capabilities that automatically determine when immediate preemption of the traffic signal is needed to allow safe, efficient movement through the intersection (e.g., lights on, sirens on, bucket up).
Orig-6	Generate and send uniform preemption requests	**Emergency Vehicle and Snowplow Operators** need mechanisms to generate and send vehicle preemption requests, when needed, in a uniform way for all intersections the vehicle may travel through.
Orig-7	Receive, consider, and respond to preemption requests	**Emergency Vehicle and Snowplow Operators** need CI capabilities at the signals that receive, consider, and respond to vehicle preemption requests, when received.

Identifier	Original User Need Title	Original User Need
Orig-8	Send and receive confirmation messages	**Emergency Vehicle and Snowplow Operators** need CIs to send and vehicles to receive messages confirming whether the vehicle preemption request was accepted or denied.
Orig-9	Determine validity of TSP and preemption requests	**IOOs Responsible for SIs** need capabilities that determine if TSP or preemption requests are valid (i.e., received from vehicles authorized to submit CIPT requests) and prevent unauthorized vehicles from requesting and receiving preferential treatment.
Orig-10	Determine if TSP requests can be granted	**IOOs Responsible for SIs** need capabilities that receive, process, and determine if valid TSP requests to adjust signal timing can be granted.
Orig-11	Track when signal preferential treatments are granted	**IOOs Responsible for SIs** need the capability to know when the valid signal preferential treatment was granted.
Orig-12	Adjust signal phasing	**IOOs Responsible for SIs** need capabilities that adjust signal phasing in response to granted TSP requests and all valid vehicle preemption requests.
Orig-13	Store and document signal preferential treatment requests and actions	**IOOs Responsible for SIs** need the ability to store and document results of the determination to grant valid TSP requests and confirm that TSP was granted.
Orig-14	Confirm appropriateness of priority or preemption	**IOOs Responsible for SIs** need a series of processes and procedures to follow to confirm that TSP or preemption requests from vehicles are handled appropriately.
Orig-15	Evaluate success	**Agency Performance Management** needs defined success metrics for CIPT systems, with defined data to evaluate success.
Orig-16	Measure and report impacts	**Agency Performance Management** has a need for dashboards or calculations of metrics that report impacts of CIPT.
Orig-17	Define anticipated uses of CIPT data	**Agency Performance Management** has a need for anticipated uses of data regarding CIPT to be defined.
Orig-18	Define data retention policies	**Agency Performance Management** needs defined data retention policies required to support data requests and uses of data.
Orig-19	Record actual CIPT data	**Agency Performance Management** has a need to record data describing priority treatments requests, responses, and priority changes implemented in response to data retention policies.

Identifier	Original User Need Title	Original User Need
Orig-20	Broadcast SPaT, MAP, and RTCM messages	**OEM and Aftermarket Providers of Vehicle Applications** need SPaT, MAP, and RTCM messages to be broadcast from each CI (i.e., in order to help RLVW application users avoid entering intersections during red signal phase).
Orig-21	Messages meet minimum requirements defined by standards efforts	**OEM and Aftermarket Providers of Vehicle Applications** need the messages broadcast from CIs to meet minimum requirements defined by the standards efforts (i.e., in order to provide assistance to RLVW application users early enough to stop safely before the intersection stop line and trust that the data received and used by the RLVW application is accurate and timely).
Orig-22	Messages contain security credentials	**OEM and Aftermarket Providers of Vehicle Applications** need the messages to contain security credentials identifying the IOO responsible for the CI (i.e., in order to help RLVW application users trust that the data received and used by the RLVW application is from a trusted source).
Orig-23	Understand if CI messages have been validated	**OEM and Aftermarket Providers of Vehicle Applications** need a mechanism to understand if a CI has been validated that it is broadcasting messages that meet minimum CTI requirements, in order to have the option of ignoring CI data from non-validated intersections.
Orig-24	Indicate a malfunction or situation causing messages to no longer be valid	**OEM and Aftermarket Providers of Vehicle Applications** need a common approach adopted by all IOOs that enables CIs to indicate a malfunction or other situation that causes either of the SPaT, MAP, or RTCM messages to no longer be valid.
Orig-25	Increase quantities of operational CIs	**OEM and Aftermarket Providers of Vehicle Applications** need increased numbers of operational CIs to support product investment and rollouts.
Orig-26	Understand CIs broadcasting validated messages	**OEM and Aftermarket Providers of Vehicle Applications** need to understand the number of CIs broadcasting messages that have been validated to meet minimum requirements defined by standards efforts.
Orig-27	Understand performance metrics	**OEM and Aftermarket Providers of Vehicle Applications** need to understand performance metrics in the initial years of CI testing validation.
Orig-28	Receive validation reports	**SCMS Providers** need to receive validation reports documenting successfully validated CIs.
Orig-29	Receive ongoing validation of operational CIs	**SCMS Providers** need ongoing validation that CIs are still operating properly.

Identifier	Original User Need Title	Original User Need
Orig-30	Provide guidance for CIs	**IOOs Responsible for SIs** need guidance on the planning, design, and deployment of CIs to guide consistent deployment that is interoperable with SCMS providers, OBUs, and RLVW applications.
Orig-31	Determine if CIs are validated	**IOOs Responsible for SIs** need a series of processes and procedures with supporting tools to determine if CIs are validated to ensure the trust of OEMs.
Orig-32	Monitor CIs	**IOOs Responsible for SIs** need industry accepted processes to continuously monitor CIs to identify indicators that the CI is no longer operating as a validated intersection.
Orig-33	Identify authenticity and origin of messages	**IOOs Responsible for SIs** need capabilities to identify the messages broadcast as authentic and originated by the IOO responsible for the CI.
Orig-34	Define success metrics for CIs	**Agency Performance Management** needs defined success metrics for operating validated CIs to encourage OEM and third-party in-vehicle RLVW applications.
Orig-35	Define anticipated uses of RLVW data	**Agency Performance Management** has a need to store data that can be used to report the number of times that malfunctions or other situations cause the SPaT, MAP, or RTCM messages to no longer be valid.
Orig-36	Define data retention policies	**Agency Performance Management** needs defined data retention policies required to support data requests and uses of data.

Table 17. Original User Needs for Interstates and Rural Corridors
Source: Athey Creek Consultants, February 2025

Identifier	Original User Need Title	Original User Need
Orig-37	Receive alerts throughout the geographic region of their trips	**All Drivers** need to be informed in a timely manner about slippery roads, high winds, and other atmospheric or pavement conditions that cause hazards throughout the entire geographic region of their trips to adjust their driving behaviors before encountering the event(s).
Orig-38	Receive advanced alerts for curves when exceeding safe speeds	**All Drivers** need to receive locally generated alerts in time to reduce speeds when they are exceeding safe speeds as they approach specifically designated areas where horizontal and vertical curves mandate speed reductions in the curves.

Identifier	Original User Need Title	Original User Need
Orig-39	Receive SWIWs	**All Drivers** need to be alerted as they are approaching SWIWs in specific key locations (where conditions merit frequent alerts and data sources are available) that describe current, accurate warnings about pavement, wind, or other conditions impacting the local area, such that they can make immediate adjustments to their driving.
Orig-40	Receive warnings about downstream hazards	**All Drivers** need to receive warnings or alerts of work zones, incidents, lane closures, speed reductions, or other hazards that are downstream to adjust speeds and be alerted to conditions.
Orig-41	Receive alerts that do not distract from driving	**All Drivers** need alerts that do not distract from driving (e.g., do not require actions, such as monitoring a mobile device, that would cause inattentive driving).
Orig-42	Avoid excessive alerts when conflicts are not likely	**All Drivers** need alerts to be silenced when no longer valid (i.e., to not be alerted excessively or when conflicts are not likely).
Orig-43	Receive safety-related situational awareness information	**Commercial Vehicle Operators** need overall situational awareness about vital information throughout the entire region that reduces safety to large trucks, such as high wind warnings, over height warnings, and road closures far enough in advance to alter trip times or routes to improve safety.
Orig-44	Receive truck parking availability information	**Commercial Vehicle Operators** need to receive information describing truck parking availability for downstream public truck parking facilities.
Orig-45	Provide a Source for reports of hazards and disruptions	**Third-Party Traveler Information Applications** (e.g., Google Maps, Waze, Apple Maps) need a source for reports of hazards and/or disruptions throughout the entire geographic region to support their routing and navigation services.
Orig-46	Generate clear, complete, unambiguous messaging	**Third-Party Traveler Information Applications** need messaging regarding reports and hazards to be clear, complete, and unambiguous to avoid inappropriate routing.
Orig-47	Generate trusted, secure messages	**Third-Party Traveler Information Applications** need sources of data to be trusted and for messages to be communicated in a secure manner.
Orig-48	Provide access to adjacent state reports	**Adjacent State DOT Centers** need access to event reports describing hazards on key routes adjacent to their jurisdiction such that they can formulate their own messages to support travelers within their states.

Identifier	Original User Need Title	Original User Need
Orig-49	Generate messages describing hazards	**Adjacent State DOT Centers** need capabilities to generate appropriate messages to describe hazards.
Orig-50	Supplement DOT operated Advanced Traveler Information Systems (ATIS)	**TMC and Traveler Information Staff** need capabilities to supplement DOT-operated ATISs to communicate in-band warnings to travelers as they approach locations of hazards.
Orig-51	Reach travelers in the geographic region through out-of-band communications	**TMC and Traveler Information Staff** need capabilities for out-of-band communications to supplement in-band communication for delivery of hazard warnings to reach travelers in the entire geographic region and those with cellular mobile devices.
Orig-52	Fuse data sources describing hazards	**TMC and Traveler Information Staff** need the capability to fuse data sources describing hazards (e.g., weather, roadway debris, objects in roadway) and generate segment-based warning messages in standard formats.
Orig-53	Verify the location of hazards	**TMC and Traveler Information Staff** need the capability to verify the location of hazards to support accurate and precise messaging.
Orig-54	Determine when hazards are resolved and terminate message dissemination	**TMC and Traveler Information Staff** need the capability to determine when hazards are resolved to enable them to terminate warning message dissemination when appropriate.
Orig-55	Control dissemination and termination of hazard messages	**TMC and Traveler Information Staff** need a capability to control when hazard messages are disseminated and when they terminate.
Orig-56	Incorporate reports from adjacent states and generate messages	**TMC and Traveler Information Staff** need the capability to receive reports from adjacent states and use the reports to automatically generate and push out messages as appropriate.
Orig-57	Use consistent definitions of what, how, and when to create standardized messages	**TMC and Traveler Information Staff** need consistent definitions of what, how, and when to create standardized messages to be delivered through IRCs.
Orig-58	Provide access to atmospheric data, pavement condition data, and condition reports from mobile devices	**TMC Weather Service Providers** (e.g., DayWeather in Wyoming, Narwhal in Utah, and the National Weather Service) need atmospheric and pavement condition data and condition reports from mobile devices to supplement existing data sources.
Orig-59	Identify validity of mobile data sources	**TMC Weather Service Providers** need a capability to identify the validity of mobile data sources.

Identifier	Original User Need Title	Original User Need
Orig-60	Fuse and resolve mobile weather reports and existing weather reports	**TMC Weather Service Providers** need a capability to fuse mobile weather reports with existing weather reporting and resolve differences.
Orig-61	Provide en-route information	**Highway Incident Responders** (e.g., DOT or State Patrol) need a capability to provide en-route information to travelers about hazards to deter traffic from hazardous events.
Orig-62	Integrate mobile data from equipped fleets	**DOT Maintenance Dispatchers and Responders** need the capability to integrate mobile data from equipped fleets into maintenance decision-making activities.
Orig-63	Monitor field device system health	**ITS Device Maintenance Staff** need a capability to monitor field device system health remotely.
Orig-64	Ensure security of roadside devices	**ITS Device Maintenance Staff** need a capability to ensure security of roadside devices.
Orig-65	Disseminate messages using network communications	**ITS Device Maintenance Staff** need a capability for warning messages to be disseminated using network communications in areas where traffic volume or geographic landscape do not support in-band communications field devices.
Orig-66	Perform OTA updates	**ITS Device Maintenance Staff** need capabilities to perform OTA updates to RSUs and OBUs.
Orig-67	Define success metrics for hazard reporting	**Agency Performance Management** needs defined success metrics for hazard reporting (e.g., percent of hazards successfully reported, average time to report, etc.) with defined data to evaluate success.
Orig-68	Create dashboards or metrics for reported hazards	**Agency Performance Management** needs dashboards or calculations of metrics reporting hazards reported or actively being reported.
Orig-69	Define data retention policies	**Agency Performance Management** needs defined data retention policies required to support data requests and uses of data.
Orig-70	Record messages generated and disseminated	**Agency Performance Management** needs records of data describing hazard messages generated and disseminated in response to data retention policies.
Orig-71	Alert drivers about roadwork events when upstream of work zones	**All Drivers** need to be alerted about roadwork events that close or realign lanes, reduce speed limits, or have workers present while they are upstream of the work zone to adjust their driving behaviors before entering the work zone.

Identifier	Original User Need Title	Original User Need
Orig-72	Alert drivers about travel delays far enough upstream to adjust travel	**All Drivers** need to be alerted to travel delays prior to departure or far enough upstream to have options to adjust travel routes or departure times.
Orig-73	Provide a source for reports in the geographic region	**Third-Party Traveler Information Applications** need a source for reports of planned or unplanned events throughout the entire geographic region to support their routing and navigation services.
Orig-74	Generate clear, complete, unambiguous messaging	**Third-Party Traveler Information Applications** need messaging regarding planned or unplanned events to be clear, complete, and unambiguous to avoid inappropriate routing.
Orig-75	Generate trusted, secure messages	**Third-Party Traveler Information Applications** need sources of data to be trusted and for messages to be communicated in a secure manner.
Orig-76	Access event reports from adjacent routes and formulate messages	**Adjacent State DOT Centers** need event reports describing planned or unplanned events on key routes adjacent to their jurisdiction such that they can formulate their own messages to support travelers within their states.
Orig-77	Generate messages describing events	**Adjacent State DOT Centers** need capabilities to generate appropriate messages to describe events.
Orig-78	Supplement DOT operated ATISs	**TMC and Traveler Information Staff** need mechanisms (e.g., third-party traveler information applications) that supplement DOT-operated ATISs to communicate descriptions and impacts of planned or unplanned events to travelers throughout IRCs in the entire region.
Orig-79	Assemble and update event reports	**TMC and Traveler Information Staff** need the capability to assemble (and update in real-time) event reports, including travel time impacts, and generate segment-based information messages in standard formats.
Orig-80	Create planned event reports for work zone events	**TMC and Traveler Information Staff** need the capability to create planned event reports for work zone events that will generate messaging, automating as much as possible.
Orig-81	Verify event reports	**TMC and Traveler Information Staff** need the capability to verify event reports to support accurate and precise messaging.
Orig-82	Receive information from vehicles approaching and in work zones	**TMC and Traveler Information Staff** need to receive information from vehicles approaching work zones and in work zones describing speeds, harsh braking, etc., that could assist in improvements to the work zones.

Identifier	Original User Need Title	Original User Need
Orig-83	Determine when events no longer impact traffic and terminate message dissemination	**TMC and Traveler Information Staff** need the capability to determine when impacts of events no longer impact traffic (daily or at termination of the event) and terminate event message dissemination.
Orig-84	Use consistent definitions of what, how, and when to create standardized messages	**TMC and Traveler Information Staff** need consistent definitions of what, how, and when to create standardized messages to be delivered through IRCs.
Orig-85	Define success metrics for event reporting	**Agency Performance Management** needs defined success metrics for planned or unplanned event reporting and dissemination.
Orig-86	Create dashboards or metrics for reported hazards	**Agency Performance Management** needs dashboards or calculations of metrics reporting events reported or actively being reported.
Orig-87	Define data retention policies	**Agency Performance Management** needs defined data retention policies required to support data requests and uses of data.
Orig-88	Record messages generated and disseminated	**Agency Performance Management** needs recorded data describing planned or unplanned event messages generated and disseminated in response to data retention policies.
Orig-89	Record messages received by OBUs and responses	**Agency Performance Management** needs records of data describing messages received by OBUs and responses (e.g., BSMs of the vehicle as captured by the OBU) on agency-owned vehicles.
Orig-90	Alert drivers when VSLs are activated and informed of current speed limit	**All Drivers** need to be alerted when VSLs are activated on their route of travel and informed of the current speed limit through roadside signing.
Orig-91	Be aware of VSLs downstream of their current location and throughout the state	**All Drivers** need a mechanism that allows them to be aware of VSLs downstream of their current location and throughout the state to plan travel.
Orig-92	Inform whether VSLs are enforceable or advisory	**All Drivers** need to be informed as to whether the VSLs are enforceable or advisory.
Orig-93	Use an approved business process that defines VSL conditions and enforceability	**TMC and Traveler Information Staff** need an approved business process that defines under what conditions speed limits are reduced, including timing of changes, increments of change, and whether speed limits are advisory or enforceable.

Identifier	Original User Need Title	Original User Need
Orig-94	Calculate VSLs based on business process and re-adjust back to posted speed limits	**TMC and Traveler Information Staff** need capabilities to calculate variable speed limits based on the business process and using weather, traffic, and event information as input to the calculation and to re-adjust back to posted speed limits, when appropriate.
Orig-95	Implement VSLs by activating VSL signs	**TMC and Traveler Information Staff** need capabilities to implement VSLs by activating VSL signs that identify the speed limit and whether it is advisory or enforceable.
Orig-96	Inform drivers in advance of reduced speeds through in-vehicle messaging	**TMC and Traveler Information Staff** need capabilities to inform drivers in advance of reduced speeds through in-vehicle messaging.
Orig-97	Initiate reduced speed limits	**Highway Incident Responders and Traffic Enforcers** (e.g., DOT or State Patrol) need a capability to initiate the implementation of reduced speed limits when they deem appropriate.
Orig-98	Inform of current VSLs	**Highway Incident Responders and Traffic Enforcers** need a capability to be informed of current variable speed limits for enforcement.
Orig-99	Provide documentation of times/dates when VSLs are implemented	**Highway Incident Responders and Traffic Enforcers** need documentation of times/dates when variable speeds were implemented for record-keeping and support of citations.
Orig-100	Collect and store data describing the dates/times VSLs were implemented	**Agency Performance Management** needs data to be collected and stored describing the times/days when VSLs were implemented.
Orig-101	Define data retention policies	**Agency Performance Management** needs defined data retention policies required to support data requests and uses of data.
Orig-102	Provide trusted and accurate sources of VSLs	**Third-Party Traveler Information Applications** need sources for VSLs that are trusted and accurate.

Table 18. Original User Needs for Vulnerable Road Users
Source: Athey Creek Consultants, February 2025

Identifier	Original User Need Title	Original User Need
Orig-103	Pass safely through intersections	**VRUs Crossing Intersections** need to be able to make safe passage through intersections while using designated lanes of travel (e.g., active crosswalks for pedestrians, bike or traffic lanes for motorized transport)
Orig-104	Make presence known in a timely manner	**VRUs Crossing Intersections** need for their presence to be known by vehicle drivers in a timely manner that allows drivers to avoid collisions.
Orig-105	Avoid performing actions when crossing	**VRUs Crossing Intersections** need to be free from performing another action that may distract them from crossing the intersection (e.g., self-reporting they are crossing or watching a system for alerts).
Orig-106	Receive alerts in time to recognize the conflict and adjust speed or trajectory	**All Drivers** approaching intersections need to be alerted when they are in conflict (e.g.., risk of collision) with a VRU early enough to recognize the conflict and adjust speed or trajectory to avoid conflicts.
Orig-107	Stop receiving alerts when the conflict no longer exists	**All Drivers** approaching intersections need alerts to cease when the risk of collision no longer exists.
Orig-108	Receive alerts that do not distract from driving	**All Drivers** approaching intersections need alerts that do not distract from driving (e.g., do not require actions, such as monitoring a mobile device, that would cause inattentive driving).
Orig-109	Avoid excessive alerts when conflicts are not likely	**All Drivers** approaching intersections need alerts to be silenced when no longer valid (e.g.., to not be alerted excessively or when conflicts are not likely) such that they ignore alerts.
Orig-110	Receive alerts when a collision with a VRU occurs	**TMC and Traveler Information Staff** need to receive alerts when a collision with a VRU occurs at an intersection or work zone.
Orig-111	Access information about collisions, alerts activated, and conflicts that generated alerts	**Safety Planners and Analysts** need information about collisions between vehicles and VRUs, the number of alerts activated, and the number of conflicts that generated alerts.
Orig-112	Receive confirmation of system performing properly and not operational	**IOO System Operators** need confirmation that systems are performing properly or when any portion of detection or alerts are not operational.
Orig-113	Perform job safely without collision with a vehicle	**VRUs in Work Zones** need to perform their job safely and without risk of a collision with a vehicle.

Identifier	Original User Need Title	Original User Need
Orig-114	Make presence known in a timely manner	**VRUs in Work Zones** need for their presence to be known by vehicle drivers in a timely manner that allows drivers to avoid collisions.
Orig-115	Receive accurate information about worker presence	**All Drivers** need accurate information as they approach work zones indicating when workers are present.
Orig-116	Know when workers are present and no longer present	**TMC and Traveler Information Staff** need the capability to know when workers are present in work zones and when they are no longer present.
Orig-117	Generate and terminate TIMs for working presence	**TMC and Traveler Information Staff** need the capability to generate TIMs to report worker presence and terminate TIMs when workers are no longer present.
Orig-118	Communicate TIMs to drivers approaching work zones	**TMC and Traveler Information Staff** need the capability to communicate TIMs to drivers approaching work zones.
Orig-119	Access information about vehicle maneuvers	**TMC and Traveler Information Staff** need information about vehicle maneuvers (e.g., harsh braking) that may indicate near misses or risks of collisions such that they can alter the work zone activities and avoid future conflicts.
Orig-120	Access information about system health	**TMC and Traveler Information Staff** need information about the health of the system.

Table 19. Original User Needs for Interoperability and Compatibility
Source: Athey Creek Consultants, February 2025

Identifier	Original User Need Title	Original User Need
Orig-121	Use consistent SPaT, MAP, and TIMs across states	**All Drivers** need SPaT, MAP, and TIMs received to be consistent in content, phraseology, and delivery time regardless of what state they are in or the system delivering the message.
Orig-122	Use consistent definitions of what, how, and when to create standardized messages	**TMC and Traveler Information Staff** need consistent definitions of what, how, and when to create standardized messages to be delivered through IRCs.
Orig-123	Make sure other states follow consistent definitions for standardized messages	**TMC and Traveler Information Staff** need other states to also follow the consistent definitions for standardized messages such that travelers are not confused by different message types as they travel in different jurisdictions.

Identifier	Original User Need Title	Original User Need
Orig-124	Need OBU manufacturers to recognize defined use of standard messages	**TMC and Traveler Information Staff** need OBU manufacturers to recognize the defined use of standard messages and include these in their OBU processing of messages received.
Orig-125	Inform other states of CTW approach and interpretation of national standards	**Other States (beyond CTW States)** need to be informed of the approach taken by CTW (and related national demonstrations of interoperability) as well as agreed interpretations of national standards.
Orig-126	Need “one voice” from industry advising on interpretation of national standards for TIM messages	**OBU and In-Vehicle Application Developers** need ”one voice” from the industry advising them on how messages defined by national standards (specifically the TIM message) will be interpreted by IOOs so they can anticipate and build hardware and software to accept and utilize these messages appropriately.
Orig-127	Display information so it is correctly interpreted	**All Drivers** need the content displayed to them by the applications that they access while traveling to correctly interpret the information communicated by DOTs, such that the navigation instructions or alerts presented to them represent the best interpretation of existing and planned conditions.
Orig-128	Verify that definitions of what, how, and when to create standardized messages will be used by third-party traveler information applications	**TMC and Traveler Information Staff** need verification whether or not third-party traveler information applications are using (or planning to use) the messages and understand the structure of the messages.
Orig-129	Deliver messages to third-party traveler information applications with common approach	**TMC and Traveler Information Staff** need capabilities to deliver messages to third-party traveler information applications using a common approach (e.g., one IOO reaches all third parties with one approach; any third party receives messages from all IOOs using the common approach).
Orig-130	Need third-party traveler information applications to recognize and interpret messages appropriately	**TMC and Traveler Information Staff** need third-party traveler information applications to recognize and interpret consistent messages appropriately.
Orig-131	Provide a forum for discussions with other V2X Accelerator program sites	**CTW Partners** need a forum for open discussions with other V2X Accelerator program sites to share their approaches to standardized message use, learn about approaches used in other sites, and resolve any discrepancies.

10. References

CAMP LLC Vehicle-to-Infrastructure (V2I-4) Consortium. (2021). *Red Light Violation Warning (RLVW) Application Vehicle System*. Retrieved January 11, 2025, from https://www.campllc.org/wp-content/uploads/sites/2896/2021/02/RLVW_ConOps_Ver_2_4_20200222.pdf?nocdn.

Institute of Transportation Engineers (ITE). (n.d.). *Connected Automated Vehicles/Connected Interoperability (CAV/CTI) Standards*. Retrieved January 9, 2025, from https://www.ite.org/technical-resources/topics/standards/cav-cti-standards/.

Panasonic. (n.d.) Concept for System Capabilities – Vulnerable Road User Safety Systems. Prepared for Utah Department of Transportation.

United Tires (UTires). (2024). *Study Reveals Where Drivers Are Most Reliant on Their GPS.* Retrieved on January 9, 2025, from https://www.utires.com/articles/where-drivers-need-gps-the-most/.

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487

www.its.dot.gov

FHWA-JPO-25-160

U.S. Department of Transportation