CONNECTED INTERSECTIONS MESSAGE MONITORING SYSTEMS REQUIREMENTS & PROTOTYPE DEVELOPMENT (CIMMS)

Final Report

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Designing for the future

FINAL

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Acronyms

BSM	Basic Safety Message
CBR	Cease Broadcast Recommendation
CI	Connected Intersection(s)
CIP	Connected Intersection Project
CV	Connected Vehicle
ECLA	External Control Local Application
IEEE	Institute of Electrical and Electronics Engineers
IOO	Infrastructure Owner/Operator
ITS	Intelligent Transportation System
MAP	MapData
OBU	Onboard Unit
OEM	Original Equipment Manufacturer
PFS	Pooled Fund Study
PSID	Product Service Identifier
RLVW	Red Light Violation Warning
RSU	Roadside Unit
SAE	Society of Automotive Engineers
SCMS	Security and Credentials Management System
SPaT	Signal Phase and Timing
TSC	Traffic Signal Controller
V2X	Vehicle-to-Everything
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure

1. Introduction

1.1 DOCUMENT PURPOSE

The Connected Intersection Message Monitoring System (CIMMS) has been developed and deployed alongside two operational connected vehicle environments in Anthem, Arizona (operated by Maricopa County DOT), and in Orem, Utah (operated by Utah DOT).

The purpose of this Final Report is to provide a description of the CIMMS system, recap each task, document the overall outcomes and findings of the project, identify lessons learned, and to provides concluding remarks.

The structure of this document is as follows:

- **Section 1** provides a document overview, and identifies all documents referenced in developing this document.
- **Section 2** describes the internal system architecture, how the CIMMS interfaces with the existing system at both deployment sites, as well as user interfaces, inputs/outputs, system reports, and operations and maintenance.
- **Section 3** provides a brief overview of each project task, the activities undertaken in each, and deliverables that were developed.
- **Section 4** provides an overview of the final outcomes and the lessons learned throughout the development, testing, and integration of the CIMMS. This section concludes with a list of development recommendations to consider for the CIMMS looking forward.
- **Section 5** provides concluding remarks about the CIMMS. The section contemplates the evolution of the CIMMS, discusses the Connected Intersections Implementation Guide (CTI 4501), and the practicality and effort required to make the changes necessary for compliance.

1.2 PROJECT SCOPE

Since the inception of Connected Vehicle (CV) technology, researchers and deployers have sought new and innovative ways to use CV to improve transportation safety, mobility, and efficiency. Most of these efforts have focused on the ability of vehicles to react to the data they receive from other vehicles and from the infrastructure. Forward Collision Warning, Red-Light Violation Warning, Curve Speed Warning, etc., are all examples of critical CV safety applications that utilize CV data and as more data becomes available, these applications continue to mature. In parallel, numerous advances to ensure timely and authenticated data is being provided to the CV environment continue. Robust fiber networks and the investment in the Security Credential Management Systems (SCMS) serve as proof of those investments. The assumption, however, has generally been that once a site had deployed and validated the broadcast messages, the data would remain correct. Two issues arise from this thinking:

- **Accuracy** – As has been the focus of the current CV PFS Connected Intersection Project (CIP), and others before it, validation of message content goes beyond conformance to the SAE J2735 standard. To truly be considered conformant to the needs of OEMs, deployers need to ensure that broadcast messages truly match what is happening at the intersection. For instance, signal indications on the traffic signal must match those in the SPAT message.
- **Consistency and Changes** – The validation of message accuracy is not only needed at the time when CV equipment is deployed, but also throughout active operations of a CV system. Signal timing patterns change, road geometries change, and devices fail – it is important to confirm that these changes are properly accounted for in the CV system simultaneously after the changes are made. Presently, only limited capabilities exist to determine if a device is even operational, so it is not a simple matter to determine if the messages a CV system produces contain data that correctly reflect ground truth.

A precursor to the CIMMS project, The CV PFS Connected Intersections Program (CIP) project[1] focused on validating a site's ability to conform to the newly published ITE CI Design Guidance[2], guidance which the OEMs agree will uniformly support advanced safety applications, such as RLVW. CIP is a validation of the guidance itself, feedback which will be provided to the industry. It's important to note that in practice, use of the guidance would typically only occur at deployment however, and similarly validate a site's ability to conform to the guidance.

But what happens after a site validates in conformance to the guidance? Agencies don't have the bandwidth or budgets to subject every intersection to the same rigors as the CIP on a repetitive basis or over an extended period of time. Many agencies are also preparing to leverage increasingly larger amounts of Vehicle-to-Everything (V2X) data from intersections and from vehicles, especially as the number of V2X-equipped vehicles increases. The Concept of Operations proposes that this V2X data can be leveraged to continuously validate the correct operation of the infrastructure over a long-term time horizon. The broad goal of the Connected Intersection Message Monitoring System is to evaluate this potential.

Note that the scope for this project (initial implementation of the message monitor) is limited to receiving CV messages from an existing CV system, and using SPaT, MAP, and BSMs (driver behavior that provides a proxy for ground truth conditions) to assess the correctness of data within SPaT and MAP messages. The ability to use driver behavior to infer ground truth is predicated on the fact that a driver's response to traffic control devices and the roadway environment is generally predictable (though not perfect). Thus, it is reasonable to assume the data in SPaT and MAP messages should be consistent with general vehicular movement as evidenced in BSMs. The correctness of data in MAP and SPaT messages was initially cited as being a priority. Limiting the message monitor to SPaT, MAP, and BSMs, as opposed to interfacing with other components in the traffic signal cabinet, simplifies the data and interfaces required between the existing system and the message monitor and minimizes the pre-requisites for the existing system. Any system for which CV data will be assessed should be able to produce and forward CV data to an external system such as the message monitor. Data from other (non-CV) sources at the intersection such as traffic signal controllers, conflict monitors, and sensing equipment (e.g. radar/LIDAR) while useful for assessing SPaT and MAP accuracy, increases

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[1] https://engineering.virginia.edu/cv-pfs-projects-and-research#accordion620710

[2] https://www.ite.org/ITEORG/assets/File/Standards/CTI%204501v0101-tracked.pdf

the complexity of the integration and/or may not be available at every intersection. Thus, data from non-CV sources was not included for the initial implementation of the message monitor.

Other needs that have been identified during this process, such as the ability to assess message performance, generic message requirements, the correctness of position correction information in the RTCM message, and the impact of position correction data on the performance of message monitor algorithms that use BSM data are documented, but not considered in the initial implementation of the message monitor. However, the message monitor will be designed in a way that allows the modification/addition of interfaces and algorithms so that data from other sources can be utilized and so other needs can be addressed in future system development efforts.

1.3 REFERENCES

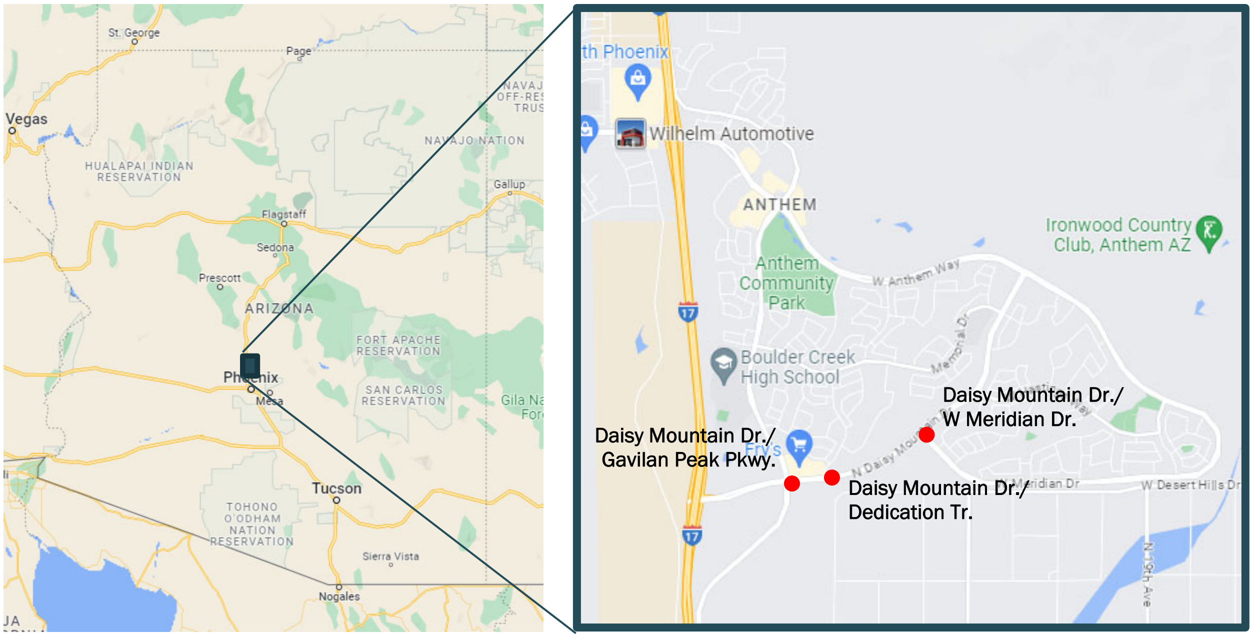
This section contains documents and literature utilized to gather input for this document.

Connected Intersection Message Monitoring System-Concept of Operations	8/2023 Update
Connected Intersection Message Monitoring System-System Requirements	12/2022 Final
Connected Intersection Message Monitoring System-Software Design	4/2023 Final
Connected Intersection Message Monitoring System-System Integration Design	10/2023 Update
Connected Intersection Message Monitoring System-System Test Plan	8/2023 Final
Connected Intersection Message Monitoring System-Assessment Report	12/2023 Draft
CV PFS Map Guidance Document https://engineering.virginia.edu/labs-groups/cvpfs	2023
SAE J2735 2016-03. V2X Communications Message Set Dictionary. https://www.sae.org/standards/content/j2735_201603/	2016
SAE J2735 2020-07. V2X Communications Message Set Dictionary. https://www.sae.org/standards/content/j2735_202007	2020
SAE J2735 2022-11. V2X Communications Message Set Dictionary. https://www.sae.org/standards/content/j2735_202211	2022
CTI 4501 v01 – Connected Intersections (CI) Implementation Guide http://www.ite.org/pub/76270782-B7E4-7F75-BC72-D5E318B14C9A	2021
CTI 4001 v01 - Roadside Unit (RSU) Standard http://www.ite.org/pub/764FB228-0F6C-BA02-6D7B-16A86B1F8108	2021
SAE J2945/B Recommended Practices for Signalized Intersection Applications https://www.sae.org/standards/content/j2945/b/	(Work in progress)
Operational Data Environment open-source decoder for MAP/SPaT/BSM https://github.com/usdot-jpo-ode/jpo-ode	2021 (latest version)
CTI 4502 v01.00 – Connected Intersections Validation Report https://www.ite.org/pub/?id=59A8D354-F7B1-6A18-6FCC-1CECE6ACDE5B	2022
Connected Intersections Program, Connected Vehicle Pooled Fund Study https://engineering.virginia.edu/labs-groups/cvpfs	

2. System Description

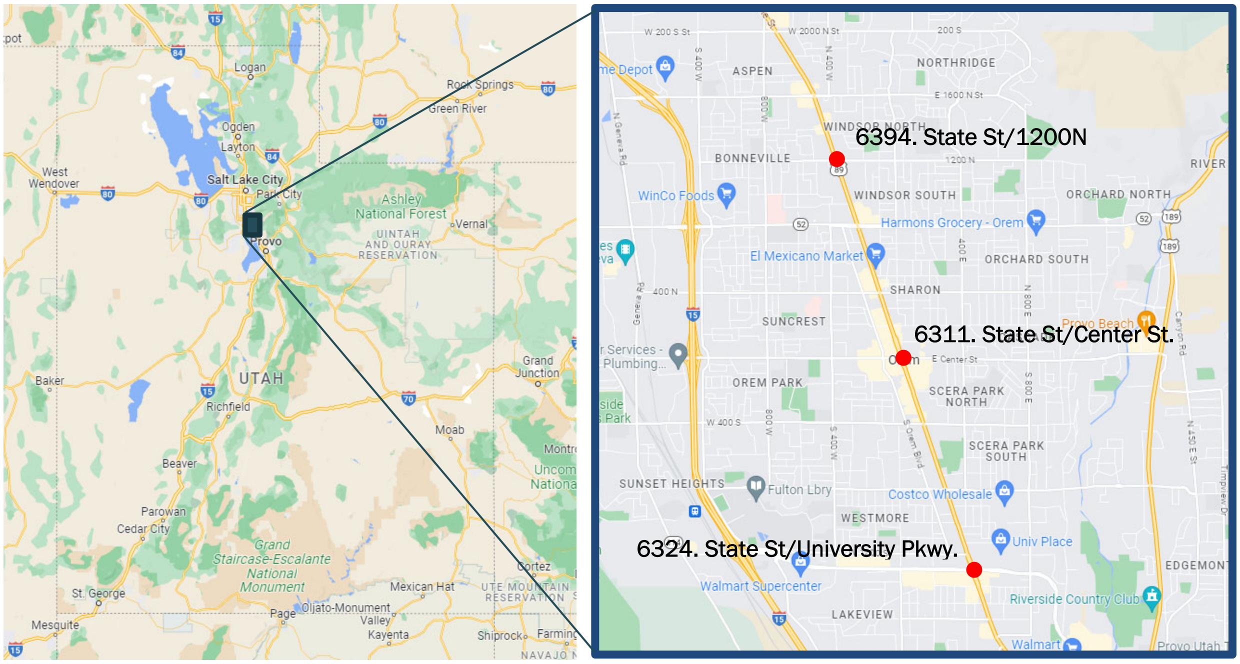
Two instantiations of the CIMMS proof of concept system were deployed. One instance interfaced with 3 network-connected Codha MK5 RSUs in Anthem, AZ (Figure 1), and the second instance interfaced with 3 Kapsch dual-mode RSUs deployed in Orem, UT (Figure 2). For the implementation in Anthem, the CIMMS was installed on virtual machines provisioned by MCDOT on a network-connected server. For the implementation in Orem, UDOT utilized a remote server hosted by Panasonic to host the virtual machines that CIMMS was installed on.

This section provides a description of the CIMMS system including the CIMMS internal architecture, the location of the CIMMS with respect to each system's existing architecture, as well as the CIMMS user interface and system outputs.



Note: Icons shown represent RSUs that interface with the CIMMS. It does not show all operational RSUs in the area.

Figure 1. Anthem, AZ RSU Locations



Note: Icons shown represent RSUs that interface with the CIMMS. It does not show all operational RSUs in the area.

Figure 2: Orem, UT RSU Locations

2.1 CIMMS INTERNAL ARCHITECTURE

The CIMMS internal architecture is comprised of several sub-components that perform various processes to meet the system requirements and software design, specified in documentation developed as part of this project. The internal architecture is provided in Figure 3, followed by a description of each subcomponent.

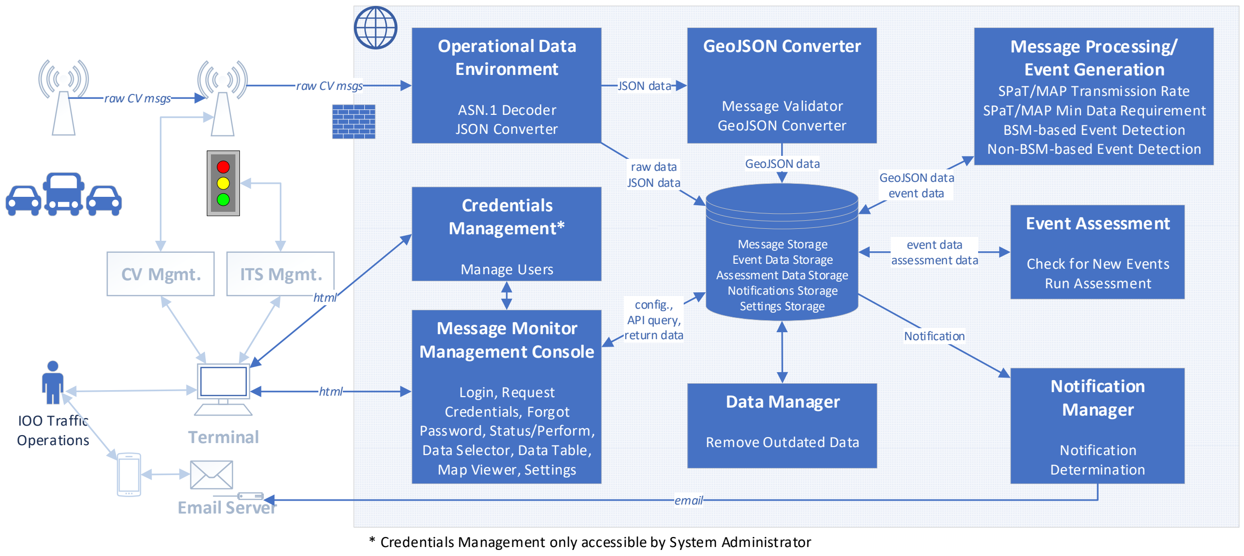


Figure 3: CIMMS Internal Architecture

Operational Data Environment (ODE) - The Operational Data Environment (ODE) is an open-source, scalable, message ingest and decoding solution for connected vehicle data. For CIMMS, the ODE is used to receive Unaligned Packed Encoding Rules (UPER)-encoded ASN.1 SPaT, MAP, and BSM messages forwarded from intersections. The ODE then decodes that data into JSON and forwards it to other CIMMS components.

GeoJson Converter – The GeoJson Converter ingests JSON encoded SPaT and MAP data from the ODE and converts it to a GeoJson encoded MAP and SPaT format (Processed MAP, Processed SPaT). The GeoJson Converter also performs message validation and normalization to streamline further processing. Note: The BSM is not converted to geoJSON.

Message Processing / Event Generation – This component utilizes algorithms to process MAP and SPaT data from the GeoJson Converter as well as BSMs from the ODE to perform continuous validation on connected intersections. User-specified parameters are used as inputs to most algorithms. It generates “events” which are stored on the database.