Development of Vehicle-to-Infrastructure Applications Program

Seventh Annual Report

July 1, 2020 through June 30, 2021

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16. Abstract

This report documents the work completed by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortia during the seventh year of the "Development of Vehicle-to-Infrastructure Applications (V2I) Program." Participating companies in the V2I Consortia (V2I, V2I-2 and V2I-3) during this period were Ford, General Motors, Hyundai Motor Group, Honda, Nissan, Toyota and VW/Audi. The period covered by the report is from July 1, 2020 through June 30, 2021. The overall goal of the V2I Program is to develop and test V2I safety, mobility, environmental and automation applications as part of the U.S. Department of Transportation (USDOT) Intelligent Transportation System (ITS) Strategic Plan. Projects active during the reporting period were the Traffic Optimization for Signalized Corridors (TOSCo), Cooperative Automated Driving Systems (CADS), Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory / Warning (QA/QW) System and Stakeholder Engagement and Outreach. This report provides a summary of key project activities and accomplishments for the period.

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Executive Summary

This document presents work carried out under the Development of Vehicle-to-Infrastructure (V2I) Applications Program (V2I Program), through Cooperative Agreement No. DTFH6114H00002, during the seventh year of program operation. The period covered by the report is from July 1, 2020 through June 30, 2021. The overall goal of the V2I Program is to develop and test V2I safety, mobility, environmental and automation applications as part of the U.S. Department of Transportation (USDOT) Intelligent Transportation System (ITS) Strategic Plan. The following material provides a high-level overview of significant activities and key findings for projects underway or completed during the Program's seventh year. Information regarding work previously completed in the V2I Program can be found in the annual reports for the prior years of operations (Shulman and Geisler, 2015, Report No. FHWA-JPO-16-263; Shulman and Geisler, 2016, Report No. FHWA-JPO-16-480; Shulman and Geisler, 2017, FHWA-JPO-18-618, Shulman and Geisler, 2018, Report No. FHWA-JPO-18-704, Shulman and Geisler, 2019, No. FHWA-JPO-19-780, and Shulman and Geisler, 2020, No. FHWA-JPO-20-819.)

V2I Program Administration

Project Status: In Progress

Project Team: CAMP LLC

Project Timeline: January 2014 – January 2022

The V2I Program Administration work order provides the mechanism to administer the Cooperative Agreement between Federal Highway Administration (FHWA) and Crash Avoidance Metrics Partners LLC (CAMP). The purpose of this work order is to:

- Establish a multi-year research program to address V2I initiatives
- Organize one or more research consortia to conduct the awarded projects
- Establish program management systems to conduct the work

Significant Activities and Key Findings to Date

- Formally organized the V2I Consortium in June 2014. The Participants in the original V2I Consortium were FCA, Ford, GM, Honda, Hyundai Motor Group, Mazda, Mercedes-Benz, Nissan, Subaru, VW/Audi and Volvo Truck. With the withdrawal of Mercedes-Benz (2014), FCA (2017),Volvo (2019), Mazda (2019) and Subaru (2019) from the V2I Consortium, the Participants continuing participation in V2I activities for the period covered by this report are Ford, GM, Honda, Hyundai Motor Group, Nissan, and VW/Audi. This Consortium represents a range of automotive perspectives as well as global viewpoints that include the U.S., Europe and Asia.
- Formally organized the V2I-2 Consortium in May 2019 to conduct the newly awarded Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone

Queue Advisory/Warning (QA/QW) System Project. The Participants in the V2I-2 Consortium are Ford, GM, Hyundai Motor Group and Toyota.

- Formally organized the V2I-3 Consortium In November 2019 to conduct the proposed Cooperative Automated Driving Systems for Improved Freeway Mobility (CADS-IFM) Phase 1 Project. The Participants in the V2I-3 Consortium are Ford, GM, Hyundai Motor Group, Nissan and VW.
- Completed the following projects:
  - Cooperative Adaptive Cruise Control (CACC) Project – completed March 2015
  - Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Approach and Eco-Departure Planning Project – completed January 2016
  - Road Weather Management Program (RWMP) Connected Vehicle-Infrastructure Research (CVIR) Project – completed June 2016
  - Advanced Messaging Concept Development (AMCD) Project - completed June 2017
  - Cooperative Adaptive Cruise Control – Small-scale Test (CACC-SST) Project – completed June 2017
  - Vehicle-to-Infrastructure (V2I) Safety Applications (SA) Projected – completed May 2019
  - Traffic Optimization for Signalized Corridors (TOSCo) Project Phase I: Modeling and Analysis – completed June 2019
  - Cooperative Automated Driving Systems for Improved Freeway Mobility (CADS-IFM) – completed July 31, 2020
  - Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (QA/QW) System Project – completed December 31, 2020
- Administered the following active projects during this annual reporting period:
  - Cooperative Automated Driving Systems for Improved Free Mobility (CADS-IFM) Project – completed July 2020
  - Stakeholder Engagement and Outreach Project – **ongoing**
  - Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (QA/QW) System Project – completed December 2020
  - Traffic Optimization for Signalized Corridors (TOSCo) Project Phase 2: Modeling and Analysis - **ongoing**

These projects are expected to enhance deployment of cooperative vehicle-infrastructure systems which will improve safety and mobility for drivers through enhancements in performance made possible by V2I connectivity. The V2I Consortia consider exploring the potential of V2I communications to improve the performance of vehicle information, warning and control systems to be high-value research, and believes that cooperative research to explore opportunities to improve safety, mobility, the environment and vehicle control are the highest priority.

Traffic Optimization for Signalized Corridors Project – Phase I

Project Status: Completed

Project Team: V2I Consortium (Ford, GM, Honda, Hyundai Motor Company, Mazda, Nissan, Subaru and VW/Audi) (Note: Mazda and Subaru elected to withdraw from the V2I Consortium at the end of 2019)

Project Timeline: April 2015 – June 30, 2019

This project addresses near-term research needs on the Eco-Signal application development roadmap established by the previously conducted AERIS Planning Study. The overall Traffic Optimization for Signalized Corridors (TOSCo) Project was planned in two phases. Phase 1 – Modeling and Analysis selected specific existing traffic corridors as potential TOSCo deployment sites, modeled the overall operating environment and developed a system design using a simulation environment that evaluated potential benefits and risks. Phase 2 – System Build and Test will implement and evaluate the system under controlled real-world conditions. The significant accomplishments and key findings to date reflect TOSCo Phase 1 activity. (Note: TOSCo Phase 2 started in the third quarter of 2019.)

Significant Accomplishments and Key Findings to Date

- Work under Phase 1 was initiated on June 13, 2016
- Created a detailed list of stakeholders needs and shared it with IOOs for input
- Identified candidate corridors for TOSCo modeling and implementation. Selected a low-speed corridor in Ann Arbor, Michigan and a high-speed corridor in Conroe, Texas.
- Completed data collection for both candidate low-speed and high-speed environments to facilitate the process of modeling the selected corridors
- Prepared and delivered an interim report on Corridor Selection and Stakeholder Needs
- Modified the project technical proposal to incorporate CACC
- Completed calibrating the simulation environments for the low-speed and high-speed corridors
- Defined the operating scenarios under which the TOSCo function is expected to operate
- Identified the high-level requirements that define the TOSCo system operation. Conducted Review Meeting #3 with FHWA to review the simulation calibration, operating scenarios and system requirements.
- Conducted Review Meeting #4 that focused on TOSCo system architecture and vehicle software algorithm modules
- Developed a detailed approach for assessing algorithm verification and performance impact for the corridor-, vehicle- and infrastructure-levels
- Completed the TOSCo Hazard Analysis / Risk Assessment (HARA) that leveraged previous work accomplished in the V2I Program's CACC Project

- Completed the initial Safety Concept
- Completed integration of CACC functionality in a fleet of four test vehicles
- Completed identification of Functional Safety Requirements
- Completed first round of CACC tests
- Completed definition of the TOSCo System Architecture
- Conducted Review Meeting #4.5 that focused on the two TOSCo system simulation models
- Completed all planned CACC testing and conducted an engineering demonstration on a test track
- Completed draft technical and cost proposals for TOSCo Phase 2 work
- Initiated TOSCo corridor simulation runs
- Conducted Review Meeting #5 that focused on traffic simulation scenarios, method to conduct traffic simulations, exceptions observed in vehicle-level simulation and CACC data analysis
- Completed TOSCo traffic-level simulation runs
- Conducted Review Meeting #5.5 to present preliminary simulation results
- Conducted Review Meeting #6 to present final simulation results
- Conducted TOSCO Phase 1 Project Summary Review
- Complete refined HARA
- Conducted coordinated testing of the CAMP CACC and FHWA platooning longitudinal control systems
- Identified additional work to be done in vehicle algorithm development and prepared execution plan
- Updated Hazard Analysis and Risk Assessment (HARA) and prepared the interim report
- Prepared CACC data files and shared with FHWA
- Delivered Corridor-level Simulation Interim Report
- Delivered Vehicle System Architecture
- Delivered Infrastructure System Architecture
- Completed vehicle algorithm refinements based on findings obtained during simulation testing
- Reassessed and refined traffic-level simulation result for the high-speed corridor based on more realistic traffic acceleration profile
- Delivered seven TOSCo reports on June 28, 2019

  - TOSCo Phase 1 Final Report
  - Traffic-level Simulation and Performance Analysis Report with Refined High-speed Corridor Results
  - Vehicle-level Simulation Report
  - Vehicle System Architecture
  - Infrastructure System Architecture
  - Functional Safety Concept and Hazard Analysis Report
  - Cooperative Adaptive Cruise Control (CACC) Vehicle Build and Testing Report
- Responded to USDOT Comments for the seven reports.
- The 508-compliant TOSCo Phase 1 Report (all seven volumes as noted above) were submitted to FHWA on May 29, 2020.

Traffic Optimization for Signalized Corridors - Phase II

Project Status: In Progress

Project Team: V2I Consortium (Ford, GM, Honda, Hyundai Motor Company, Nissan, and VW/Audi)

Project Timeline: July 2019 – December 2022

The Traffic Optimization for Signalized Corridors (TOSCo) Phase II is the chronological progression of the initial Planning Study and Phase I – Modeling and Analysis of the near-term research plan. This project covers Phase II – System Build and Test of the near-term TOSCo research plan which will implement, verify and deploy the proposed system developed during Phase I along the State Highway 105 traffic corridor in Conroe, Texas that was modeled in simulation to estimate potential benefits and refine the TOSCo system design.

Significant Accomplishment and Key Findings to Date

- Work under Phase II was initiated on July 1, 2019
- A project kick-off meeting was conducted on July 30, 2019
- Initiated work to:
  - Improve TOSCo vehicle algorithm
  - Build four vehicles with TOSCo capability
  - Build 10 portable On-board Equipment (OBE) units
  - Create Signal Phase and Timing (SPaT) to include Back of Queue (BOQ) and TOSCo-specific regional extension for Green Window Start / End times
  - Integrate Texas Transportation Institute's (TTI) queue detection algorithm into vehicle-level simulation

    - Develop performance analysis plan
    - Integrate Denso software contribution into vehicle-level simulation
- Updated key stakeholder on TOSCo progress
- Built four vehicles with TOSCo capability
    - Converted two existing CACC vehicles and built two new vehicles
- Created SPaT to include BOQ and TOSCo-specific regional extension for Green Window Start / End
- Continued integrating TTI queue detection algorithm into vehicle-level simulation
- Developed initial version of performance analysis plan
- Conducted Review Meeting 6.5 (December 6, 2019)
- Integrated Denso software contribution into vehicle-level simulation
- Completed portable OBE builds
- Procured/repurposed a representative set of infrastructure equipment
- Completed activities associated with the following subtasks:
    - 9.1: Develop TOSCo OBE Functionality
    - 9.2: Upgrade CACC Vehicles to TOSCo Capability
    - 9.4: Additional TOSCo Prototype Vehicle Build(s)
    - 9.5: Develop Portable OBEs
    - 10.1: Build Infrastructure Components
- Updated key stakeholders on TOSCo progress
- Completed integration and verification of TTI's detector-based queue detection algorithm into the vehicle-level simulation environment (Subtask 9.6)
- Initiated Subtask 9.7 to integrate Denso software module, integrated vehicle controller and infrastructure algorithm to thoroughly examine and refine the subsystem software prior to on-road testing
- Developed Initial System Verification Plan (Subtask 11.1)
- Developed initial data needs for System-level Test (Subtask 12.1)
- Developed initial System-level Performance Analysis Plan (Subtask 12.1)

- Completed integration of OBE software module, integrated vehicle controller and infrastructure algorithm to thoroughly examine and refine the subsystem software prior to on-road testing (Subtask 9.7)
- Conducted TOSCo Review Meeting #7 on August 5, 2020 covering activities in the following subtasks:
    - Subtask 10.2: Implement TOSCo Functionality
    - Subtask 10.3: Verify Infrastructure Subsystem(s) in Controlled Setting (RELLIS Campus with V2I Pods)
    - Subtask 9.7: Verify / Refine Combined Vehicle Software in Simulation
    - Subtask 11.1: Establish System Verification Plan (RELLIS Testing with TOSCo Vehicles)
    - Subtask 12.2: Update Corridor Simulation Models
- Completed first round of closed-course vehicle subsystem testing (Subtask 9.3)
- Updated key stakeholders on TOSCo progress
- Harmonized CLAUNCH performance of TOSCo vehicles at Milan Dragway in Michigan (test facility)
- Revised Dedicated Short-range Communications (DSRC) antenna models and mounting position in IAV's Mobile Intelligent Infrastructure (MII) and one of the vehicles to maximize range by using newest MobileMark DSRC antennas
- Revised TOSCo vehicle algorithm and verified performance using the vehicle-level simulation environment as necessary towards Test 2 (targeted February 2021)
- Completed planned work to exercise a combined version of the vehicle subsystem software utilizing a revised vehicle-level simulation environment representing an intersection along the SH105 corridor in Texas
- Completed second round of vehicle testing at FT Techno of America, Fowlerville Proving Ground. This completes vehicle subsystem verification.
- Completed infrastructure subsystem testing with hardware modifications to accommodate the shift in corridors from SH105 to FM 1960. This completes infrastructure subsystem verification.
- Obtained letter of support from Texas Department of Transportation (TxDOT) in support of TOSCo field testing on alternate FM 1960 Corridor
- Shipped TOSCo vehicles to TTI
- Updated key stakeholders on TOSCo progress

- Completed three rounds of integration testing at the Texas A&M RELLIS facility in April, May and June
- Implemented vehicle algorithm modifications for risk mitigation
- Completed infrastructure equipment procurement
- Secured infrastructure installation contractor
- Completed infrastructure deployment schedule
- Conducted maintenance on TOSCo vehicles and transported to RELLIS campus in Texas

Cooperative Automated Driving Systems (CADS)

Project Status: Concluded July 31, 2020

Project Team: V2I-3 Consortium (Ford, GM, Hyundai Motor Group, Nissan and VW)

Project Timeline: July 2018 – July 31, 2020

The objectives of this project were to facilitate collaboration and sharing of research results between CAMP, the USDOT and other interested stakeholders to provide input to USDOT's cooperative automation research roadmap, identify areas for potential collaboration and begin the process of cooperatively developing and evaluating promising Cooperative Automated Driving Systems (CADS) technology. This effort supported the implementation of Connected Automated Vehicle (CAV) systems by engaging multiple OEMs, suppliers and Infrastructure Owner and Operators (IOOs) in the system definition process.

Significant Accomplishment and Key Findings to Date

- Participated in the FHWA National Dialogue on Highway Automation sessions on:
  - Planning and Policy, June 26-27, 2018 in Philadelphia, Pennsylvania (Workshop #1)
  - Digital Infrastructure and Data, August 1-2, 2018 in Seattle, Washington (Workshop #2)
  - Freight, September 5-6, 2018 in Chicago, Illinois (Workshop #3)
  - Operations, October 24-25, 2018 in Mesa, Arizona (Workshop #4)
  - Infrastructure Design & Safety, November 14-15, 2018 in Dallas, Texas (Workshop #5)
- Held discussions with FHWA to review the USDOTs draft roadmap for CAV research
- Held a concept of framing discussion with FHWA staff to initiate work on a high-level Concept of Operations (ConOps) for a CADS to improve freeway mobility
- Developed a draft ConOps describing CADS for Improved Freeway Mobility (CADS-IFM)
- Provided a project overview briefing to the IOO/OEM Forum

- In specific sessions, reviewed draft ConOps with FHWA and with the IOO/OEM Forum – Connected Automation Work Group
- Provided a draft follow-on project proposal to FHWA for discussion
- Completed the high-level ConOps, System Requirements and Hazard Analysis for Improved Freeway Mobility using Cooperative Automation
- Held a workshop with FHWA staff to review CAMP's IFM concept development and FHWA Cooperative Driving Automation research involving the Cooperative Automation Research Mobility Applications (CARMA) Platform and CARMA Cloud
- Proposed a draft framework for integrating IFM with CARMA's Integrated Highway Prototype (IHP) efforts
- Held a workshop with FHWA staff to summarize the Concept of Operations and System Requirements Allocation for IFM and review application of the Functional Safety Process
- Delivered documentation of the Concept of Operations, High-level Requirements, Hazard Analysis and Functional Safety Concept for IFM
- Submitted the Improved Freeway Mobility (IFM) using Cooperative Automation Phase 1 Modeling and Analysis Technical Proposal Volume 1
- Submitted the Integrated Highway Prototype (IHP) Collaboration Technical Proposal Volume 1
- Submitted the Improved Freeway Mobility (IFM) using Cooperative Automation Phase 1 – Modeling and Analysis Technical Proposal Volume 1

Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (QA/QW) System

Project Status: Concluded December 2020

Project Team: V2I-2 Consortium (Ford, GM, Hyundai Motor Group and Toyota)

Original Project Timeline Phase 1 & 2: May 2019 – November 2021

Amended Project Timeline Phase 1: May 2019 – September 2020 (USDOT elected to not fund Phase 2)

The purpose of the Event-Driven Configurable Messaging (EDCM) Project was to develop and implement an architecture to support flexible message scheme with the ability to dynamically adjust two-way data exchange between equipped vehicles and a Traffic Management Center (TMC).

In May 2019, the V2I-2 Consortium conducted the Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (QA/QW) System Project. The Participants in the V2I-2 Consortium were Ford, GM, Hyundai Motor Group and Toyota.

Significant Activities and Key Findings to Date

- Project Kickoff Meeting – June 2019
- Established weekly technical team meetings consisting of CAMP, Suppliers, Connected Vehicle (CV) Pooled Fund Study (PFS) Project lead and members from the FHWA team
- Virginia Tech Transportation Institute (VTTI) conducted four workshops in cooperation with the Virginia Department of Transportation (VDOT) in four out of the nine districts in Virginia
    - Salem, Virginia – August 15, 2019
    - Northern Virginia (NoVA) – August 26, 2019
    - Richmond, Virginia – August 29, 2019
    - Hampton, Virginia – October 1, 2019
- The Technical Management Team (TMT) evaluated various languages to support query and a response message that is flexible and scalable for broad spectrum of use cases and for conditional queries from the TMC. The team selected eXtensible Markup Language (XML) for the purpose.
- The TMT developed a high-level messaging structure for DQM using XML and required schema definition for the XML.
- The TMT held discussions about the QA/QW application and system-level requirements with the Connected Vehicle Pooled Fund Study (CV FPS) leads in support of the ConOps
- Presented the EDCM Project technical update at the CV PFS face-to-face meeting on December 11, 2019 in Tampa, Florida
- Completed Use Case workshop in October 2019
- Completed Design Review 1 on October 2019
- Developed XML for Query Message (QM) from the TMC and Query Response (QR) from the vehicle
- Developed XML schema to describe and validate the structure and the content of XML elements, attributes and data types
- The development of QM XML for several use cases were identified from the VDOT workshops and were tested for correctness of the message against the defined schema
- Completed the EDMC ConOps document
- The TMT defined system requirements for the QA/QW application to support low- and high-fidelity application in the vehicle
- Developed requirements for query and response messages for the TMC including data sampling for QA/QW at a work zone for high-fidelity use cases

- The TMT developed required data elements for Road Safety Message (RSM) to support in-vehicle QA/QW application
- Results of the traffic congestion and formation of queue(s) analysis data collection were presented at the CV PFS meeting on December 10, 2019 in Tampa, Florida
- Presented the EDCM Project and proposed data elements for QA/QW application for J2945/4 RSM at the SAE Infrastructure Applications Technical Committee Face-to-Face Meeting on February 11, 2020 in Anaheim, California
- VTTI implemented software for message parsing for QM and RM for bench testing
- VTTI implemented communication software for bench testing to emulate TMC back-office communication interface with CV and information processing of RM
- The TMT documented the system requirements for the QA/QW application to support low- and high-fidelity applications in the vehicle
- The TMT developed requirements for query and response message for the TMC including data sampling for QA/QW at a work zone for high-fidelity use cases and required data elements for RSM to support the in-vehicle QA/QW application
- The TMT developed XML schema for QM and QR for Tasks 4A, 4B and 4C to allow for the setting of geographical and vehicle dynamic data request from vehicles as desired by the TMC for region of interest and application. The schema was tested for use cases that were identified from the VDOT workshops.
- The VTTI software development team implemented communication protocol for establishing TMC connectivity with CV's for the reference bench test system and developed a TMC back-office communication interface with CV for QM and information processing of RM
- Completed the QA/QW Application System Requirements Document in coordination with CV PFS companion project
- The software team at VTTI developed an end-to-end reference bench test system for creation and transmission of the QM within the context of how a TMC might operate based on six use cases selected to represent the conditions of interest to the stakeholder
- The TMT reviewed and provided comments to the Connected Vehicle Pooled Fund Study (CV PFS) companion project on V2I Queue Advisory/Warning Applications: concept and Design
- The Final Project Briefing was conducted on July 16, 2020 to USDOT/FHWA.
- The following four reports documenting the EDCM Phase 1 were developed and posted on the CAMP website. Links to download the reports were provided to FHWA.
    - Event Driven Configurable Messaging (EDCM) Concept of Operations – Version 1.6
    - Queue Advisory & Queue Warning (QA/QW) System and In-vehicle Application Requirements

- Event Driven Configurable Messaging (EDCM) Phase 1
- Event Driven Configurable Messaging (EDCM) Schema

Stakeholder Engagement and Outreach

Project Status: Awarded March 2019

Project Team: V2I Consortium (Ford, GM, Honda, Hyundai Motor Company, Nissan, and VW/Audi)

Project Timeline: March 2019 – January 2023

This project addresses the continued need for Vehicle-to-Infrastructure (V2I) Deployment Support beyond the current and future proposed FHWA / CAMP V2I Projects. The objectives of the project are for the continued facilitation, collaboration and support with a broad range of stakeholders and partners as necessary to implement the results of the V2I projects and identify additional needs.

Significant Activities and Key Findings to Date

- Developed a high-level ConOps for RSZW from the operator's perspective
- Reviewed IOO experiences with the mapping tool chain developed by CAMP under the V2I-SA Project
- V2I-SA Project Principal Investigator (PI) was Chair of SAE Technical Committee (TC) on Traffic Signal Applications. The TC worked on the development of the following:
  - SAE J2945/10 – MAP/SPaT Deployment – Intersection Operations
  - SAE J2945/11 – Signal priority and preemption
- V2I-SA Project PI was Chair of Mapping Task Force under Infrastructure Applications Technical Committee. The TC worked on the following:
  - Mapping for current and future Connected Vehicle (CV) applications
- The Mapping Tool Chain is now embedded in FHWA Work Zone Data Collection (WZDC) Tool providing both RSMs for local broadcast and Work Zone Data Initiative (WZDI) compliant data
- "Encouraging Use of Work Zone Mapping Tools – Request for IOOs" document developed and presented at the CAT Coalition Strategic Initiatives Webinar on July 23, 2020 along with a WZDC tool overview provided by FHWA
- Monitored implementation to collect lessons learned from testing in Texas, Arizona and California
- Encouraging coordination between WZDI v3.0 and SAE J2945/4 Roadside Safety Message (RSM) standards activities
- Reviewed connected work zone testing experience in Florida and Virginia
- Developed outreach material to promote additional field deployments of connected work zones

- Developed a white paper describing levels of work zone data and supported functionality to encourage coordination of WZDI and SAE J2945/4 standards initiatives (includes feedback from Volpe)
- Developed a summary presentation of "Connected Work Zones: Lessons Learned Thus Far" in lieu of a white paper capturing work in Arizona and Texas. Awaiting input from California and Virginia.
- As part of the support for the IOOs, the following activities occurred:
    - Reviewed and updated the SPaT/MAP Verification Tool and Clarifications for Consistent Implementations (CCI) document
    - Provided connected Work Zone (WZ) Mapping S/W Toolchain support to Saxton Transportation Operations Laboratory (STOL) and the University of Arizona (Maricopa County)
    - The CAMP V2I Safety Applications (V2I-SA) Toolchain was made available for download on CAMP's website (www.campllc.org)
    - The CAMP V2I-SA Toolchain was also provided to STOL for integrating into the mapping toolset with the intersection mapping tool developed by Leidos at STOL
    - The V2I-SA Toolchain was presented at the Automated Vehicle Symposium in the Advanced Smart Work Zone Solutions panel on Work Zone Data Exchange on July 17, 2019
    - The Model Concept of Operations describing an Infrastructure System to Support the Reduced Speed Zone Warning – Lane Closure Application is now posted on the National Operations Center of Excellence (NOCoE) website
    - The V2I-SA Toolchain was presented at the NOCoE Webinar on November 22, 2019 to share lessons learned and included the relationship to Work Zone Data Initiative (WZDI) and lessons learned from initial utilization in Texas and Arizona
    - Developed the document entitled "Test Procedures for Verifying SPaT and MAP Messages." The document was presented at the Connected Fleet Challenge webinar on November 21, 2019.
    - Developed a draft in-vehicle application category definition of work zone map messages to support Traveler Information / Driver Information / Driver Warning.
    - Reviewed WZDx v2.0 definitions vs SAE J2945/A.
    - Established a dialogue with SAE IA TC to discuss map data needs to support in-vehicle applications.
    - Engaged the FHWA V2X Mapping Project as a potential source of enhanced mapping tools and support.
    - A CAMP Proposal was developed to assist and complement the Mcity/CV PFS Projects focus on development of functional safety, test procedures and test tools.

- As part of the support for Standards Development, the following activities occurred:
    - The document originally entitled “Recommended Best Practices for MAP-SPaT Message Deployment” was renamed to “MAP-SPaT Message Deployment – Intersection Operations” by the Traffic Signal Application (TSA) Technical Committee (TC) under J2945/A. The document included minimum performance requirements and implantation guidance.
    - The Infrastructure Application (IA) and Traffic Signal Application (TSA) Technical Committees merged under the name of Intersection Application (IA) at the February 11, 2020 face-to-face meeting.
    - The final version of J2945/3 (Road Weather) was reviewed for ballot and approved.
    - In the Infrastructure Applications Technical Committee (IATC), Purser Sturgeon conducted requirements and Needs to Requirement Traceability Matrix for J2945/4 (Roadside Safety Message).
    - Work continued to define user needs and mapping layer architecture for J2945/A – Next generation mapping for connected Vehicle-to-Everything (V2X) applications.
    - Presented ITE Connected Intersection (CI) update at the IATC meeting in support of J2945/B (Recommended Practices for Connected Signalized Intersection Applications). Focus was on RLVW application testing needs.
    - CAMP provided EDCM Phase 1 documents for query messaging and response for V2X application to SAE IATC document sponsor for J2945/C Traffic Probe Use and Operation for system design.
    - Conducted a walkthrough of J2945/C system design.
    - Roadside Unit (RSU) Standardization – user needs, requirements and Needs to Requirements Traceability Matrix (NRTM) completed.
    - Completed ConOps user needs for the Connected Intersection (CI).
    - Roadside Unit (RSU) Standardization – The System Design Document walkthrough for the RSU Project was conducted from December 1 through December 3, 2020.
    - Connected Intersection (CI) – The Requirements Document walkthrough for the CI Project was conducted on December 7 through December 10, 2020.
    - Connected Intersection (CI) – The System Design Detail Document walkthrough for the CI Project was conducted on March 8 through March 11, 2021.
    - Fifteen agencies responded to the solicitation of interest for verifying needs, requirements and design as specified in the CI Implementation Guide. Due to limited resources and time, four agencies were selected for field test and verification. Requirements for self-test and verifications were provided to the other 11 agencies.
    - The 28-day ballot for SAE J2945/4 (Road Safety Message) ended on May 10, 2021. It was approved by 68.6%.

- The committee approved the document ballot for SAE J2945/C (Vehicle Probe Data and Use) on January 14, 2021, and the Comment Resolution was completed with the second ballot ending on April 26, 2021. It was approved by 88.9%.
- Conducted ConOps Stakeholder Review Meeting on May 17 and May 18.
- ASN.1 Object definitions progress started.
- The Roadside Unit (RSU) Standardization Draft V01 was published at the ITE website.
- Fifteen sites from 13 participating organizations are providing intersection field test data for analysis and validation of SPaT and MAP messages as per the CI Implementation Guide for RLVS. Participating organizations will continue to collect field test data for validation until end of July for analysis and verification.

1 V2I Program Administration

This document presents the Seventh Annual Report for the Development of Vehicle-to-Infrastructure (V2I) Applications Program (i.e., the V2I Program). The V2I Program is sponsored by the Federal Highway Administration (FHWA) through Cooperative Agreement No. DTFH6114H00002. The period covered by this report is from July 1, 2020 through June 30, 2021. The overall goal of the V2I Program is to develop and test V2I safety, mobility, environmental and automation applications as part of the U.S. Department of Transportation (USDOT) Intelligent Transportation System (ITS) Strategic Plan. The program is administered by Crash Avoidance Metrics Partners LLC (CAMP) under the Program Administration work order. This work order will run throughout the V2I Program. The purpose of the work order is to:

- Establish a multi-year research program to address V2I initiatives
- Organize one or more research consortia to conduct the awarded projects
- Establish program management systems to conduct the work

The V2I Consortia were formed to conduct the projects awarded under the Cooperative Agreement. The V2I Consortium Participants during the period of this report are Ford, GM, Honda, Hyundai Motor Group, Nissan and VW/Audi. Current V2I-2 Consortium Participants are Ford, GM, Hyundai Motor Group and Toyota. Current V2I-3 Consortium Participants are Ford, GM, Hyundai Motor Group, Nissan and VW/Audi. The Consortia represent a range of automotive perspectives from manufacturers as well as global viewpoints that encompass the United States, Europe, and Asia. The Consortium Management Committees (CMC) meets on a regular basis to review progress within the individual projects, assess the status of deliverables and milestones, and address strategic items affecting the overall V2I Program.

The following projects were active during the reporting period:

- Traffic Optimization for Signalized Corridors (TOSCo) Project Phase 2: System Build and Test
- Cooperative Automated Driving Systems (CADS) Project – Project completion was July 31, 2020
- Stakeholder Engagement and Outreach Project
- Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (WA/QW) System Project – Project completion was 12/31/2020

Summaries of the activities and accomplishments within these projects are contained in material found later in the report.

The projects undertaken through the V2I Program are expected to enhance deployment of driver assistance systems to potentially improve safety and mobility for drivers through improvements in performance made possible by V2I connectivity while also exploring enhancements to situational awareness possible through improved knowledge of the driving environment. The V2I Consortium

considers exploring the potential of V2I communications to improve the performance of vehicle information, warning and control systems to be high-value research. The V2I Consortium believes that cooperative research to explore opportunities to potentially improve safety, mobility, the environment and vehicle control are the highest priority. The overall program administration activities are contained in the follow task:

- Program Administration (Task 1): This task will contain the activities associated with the overall management of the V2I Program and continue the efforts started at Program inception.

A summary of the activities in the V2I Program Administration Work Order are provided below.

Program Administration

The following deliverables were prepared and submitted to FHWA as part of the work completed during the period of performance of this report:

- Completed the Quarterly Status Reports which summarize progress in active projects within the V2I Program by calendar quarter. The Quarterly Status Reports were submitted to FHWA on July 30, 2020, October 30, 2020, January 30, 2021 and April 30, 2021.
- Completed the Quarterly Progress Briefings which provide a presentation to FHWA of the work performed in the preceding quarter. Quarterly Progress Briefings were completed on July 16, 2020, October 28, 2020, January 21, 2021 and April 20, 2021.
- Completed the V2I Risk Log which consolidates the identified risks for each active project into one report along with the proposed mitigation plans. The consolidated Risk Log was updated quarterly and submitted concurrently with the Quarterly Status Reports.
- Completed the Sixth Annual Report for the V2I Program (Shulman and Geisler, 2019, Report No. FHWA-JPO-20-819).
- Prepared and submitted the Annual Personal Property Inventory on November 12, 2020.
- Prepared and submitted the Annual Equipment Inventory on November 12, 2020.
- Conducted the CY2020 Annual Budget Review and Program Plan on November 16, 2020.

Information regarding work previously completed in the V2I Program can be found in the annual reports for the prior years of operations (Shulman and Geisler, 2015, Report No. FHWA-JPO-16-263; Shulman and Geisler, 2016, Report No. FHWA-JPO-16-480; Shulman and Geisler, 2017, FHWA-JPO-18-618, Shulman and Geisler, 2018, Report No. FHWA-JPO-18-704, Shulman and Geisler, 2019, Report No. FHWA-JPO-19-780, and Shulman and Geisler, 2020, No. FHWA-JPO-20-819).

2 Traffic Optimization for Signalized Corridors Project

This project addresses near-term research needs on the Eco-Signal application development roadmap established by the previously completed CAMP Applications for the Environment: Real-Time Information Synthesis (AERIS) Planning Project (April 2015 – June 2016). The Traffic Optimization for Signalized Corridors Project[1] is a joint effort between the V2I Consortium, Texas Transportation Institute (TTI), the University of Michigan Transportation Research Institute (UMTRI), and the University of California Riverside (UCR). TOSCo uses wireless data communications from Roadside Units (RSUs) to connected vehicles to optimize mobility, fuel economy and emissions while traveling along urban corridors of equipped signalized intersections. The project was planned in two phases. Phase 1 – Modeling and Analysis (July 2016 – June 2019) selected specific existing traffic corridors as potential TOSCo deployment sites, modeled the overall operating environment and developed a system design using a simulation environment that evaluated potential benefits and risks. Phase 2 – System Build and Test (July 2019 – December 2021) will implement and evaluate the system under controlled real-world conditions.

Traffic Optimization for Signalized Corridors Project – Phase 1

As the TOSCo Project Phase 1 – Modeling and Analysis concluded on June 30, 2019, the following reports were submitted to FHWA on June 28, 2019:

- Traffic-level Simulation and Performance Analysis Report with Refined High-speed Corridor Results
- Vehicle-level Simulation Report
- Vehicle System Architecture
- Infrastructure System Architecture
- Functional Safety Concept and Hazard Analysis Report
- Cooperative Adaptive Cruise Control (CACC) Vehicle Build and Testing Report
- TOSCo Phase 1 Final Report

[1] In November 2017, this project underwent a name change. Previously, the project was known as the Cooperative Adaptive Cruise Control (CACC)-Enabled Eco-Approach and Eco-Departure Small-scale Test and Evaluation Project.

The 508-compliant versions of the above TOSCo Phase 1 Reports were delivered to FHWA on May 29, 2020.

Simulation Modeling and Performance Analysis (Task 3)

This task lays the foundation for developing simulation models of actual urban corridors that possess the environmental attributes important to the operation of a TOSCo system as identified by the Project Team.

System Architecture and Algorithm Development (Task 4)

The objective of Task 4 was to establish the TOSCo system architecture and develop the vehicle and infrastructure algorithms needed to support TOSCo functionality. The architecture and algorithms were then be incorporated into the simulation environment developed under Task 3.

System Specification and Hazard Analysis (Task 5)

The objectives for this task were to create and refine a TOSCo system specification, documenting the TOSCo functionality developed and evaluated. A 'safety concept' was also developed for the proposed TOSCo system that addressed both in-vehicle and infrastructure components. The overall TOSCo system specification was reviewed for potential hazards and functional requirements were refined to mitigate risks on an ongoing basis throughout the project.

TOSCo Phase 2 Planning (Task 6)

Draft technical and cost proposals for the TOSCo Phase 2 Project were completed and delivered to the FHWA on March 29, 2018. At the request of FHWA, the Project Team revised the cost and technical proposals and resubmitted them on July 31, 2018. The revised proposal involved splitting the Phase 2 Period of Performance (POP) into two one-year terms with added milestones and deliverables to define the two terms. The proposal was approved and awarded on June 14, 2019.

Coordination and Outreach (Task 7)

Under this task the TOSCo Project Team interacted with other relevant USDOT programs and projects in order to successfully execute the tasks and activities within Phase 1.

Implement CACC in Test Vehicles (Task 8)

The objective of this task was to implement and debug the CACC algorithms developed in the simulation environment during the previous CAMP Cooperative Adaptive Cruise Control Small-Scale Test (CACC-SST) Project Phase 1 in at least two but no more than four of the existing Adaptive Cruise Control (ACC)-equipped vehicles. Testing in this task verified correct operation of the CACC vehicle system.

Traffic Optimization for Signalized Corridors Project – Phase 2

The following is the chronological progression of the initial Planning Study and Phase 1 – Modeling and Analysis of the near-term research plan. This covers the Phase 2 – System Build and Test of the near-term Traffic Optimization for Signalized Corridors (TOSCo) research plan which will implement,

verify and deploy the proposed system developed during Phase 1 along the State Highway 105 traffic corridor in Conroe, Texas that was modeled in simulation to estimate potential benefits and refine the TOSCo system design.

Due to the COVID-19 Pandemic, this project was extended beyond its original end date of December 2021 to December 2022 (includes 6-month close out period).

Technical Project Management (Task 1)

The project team met weekly in dedicated technical meetings instituted to address Task 9 (Implement TOSCo in Vehicles), Task 10 (Implement TOSCo in Infrastructure Components), Task 11 (System Verification and Refinement) and Task 12 (Performance Assessment).

The project team encountered significant impacts to the project schedule due to actions taken at organizational and local, state and federal government levels as a result of the COVID-19 Pandemic. The affected subtasks were 9.3, 9.6, 10.2, 10.3, 11.1, 12.2 and 12.3. The project team was able to execute vehicle and infrastructure subsystem verification test plans and debug activities on a limited scale at the TTI RELLIS Campus and IAV's headquarters in Germany. The team developed and implemented a contingency plan to address time lost due to the COVID-19 Pandemic. This plan extends the overall Phase 2 Project timeline by 6 months. Updates to individual subtasks timing are indicated in the following sections.

Coordination and Outreach (Task 7)

The project team interacts with other relevant USDOT programs and projects to execute the tasks and activities described within the technical proposal in a successful and timely manner and within the stated budget. The project team understands that such coordination and frequent ongoing interactions are essential and will identify the needed interactions on an on-going basis. Under Task 7, the project team will maintain coordination and interactions as the project progresses.

2.1.1.1 Stakeholder Interaction & Coordination with Related Efforts (Task 7.4)

During the first reporting quarter for this report, the project team provided a TOSCo overview to the CAMP Safely Operating Automated Driving Systems (SOADS) in Challenging Dynamic Scenarios Consortium on July 29, 2020. The project team conducted a workshop to the IEEE ITSC on September 20, 2020 entitled "TOSCo Traffic Simulation Methodology." Meetings were held with the IOO/OEM Forum Connected Automation Working Group in July, August and September. A presentation of an overview focusing on implementing TOSCo in infrastructure components was presented during the August meeting.

During the second reporting quarter for this report, the project team continued to meet with key members of the IOO/OEM Forum Connected Automation Group at the monthly meetings in October, November and December and shared an overview focusing on TOSCo system verification testing and refinement during the October meeting.

The project team presented an overview focusing on TOSCo Hazard Analysis/Risk Assessment (HARA) during the January meeting of the IOO/OEM Forum Connected Automation Group. The team continued to meet during the third quarter at the monthly meetings in February and March. The team also coordinated with the Houston District to secure a letter of support of TOSCo testing to be performed on the FM 1960.

During the final reporting quarter for this report, the project team presented an overview of the TOSCo testing at the Texas A&M RELLIS facility during the May 2021 meeting. The team also coordinated a "virtual" demonstration of TOSCo functionality with FHWA. Activities concluded in coordinating with TxDOT and the traffic signal equipment suppliers on FM 1960 deployment as well as working with Connected Vehicle Pooled Fund Study (CV PFS) to coordinate a demonstration to be held in March 2022.

Implement TOSCo in Vehicles (Task 9)

The objectives of Task 9 are the transfer of the vehicle control algorithms developed in Task 4 of the TOSCo Phase 1 Project from the vehicle-level simulation environment into the prototype CACC vehicles verified under Task 8 of the TOSCo Phase 1 Project and upgrade these vehicles to be fully-TOSCo capable. It will be necessary to verify the capability of the existing prototype CACC vehicles to support full TOSCo functionality. It is anticipated that some vehicles may need to be replaced to support the TOSCo Creep and Coordinated Launch operating modes.

Develop TOSCo Onboard Equipment (OBE) Functionality (Task 9.1)

This subtask concluded on February 29, 2020.

Upgrade CACC Vehicles to TOSCo Capability (Task 9.2)

This subtask concluded February 29, 2020.

Verify Vehicle Subsystem in Controlled Setting (Task 9.3)

During the first quarter of this report, the TOSCo Project Team refined the DENSO OBE algorithm based on two rounds of testing on the IAV test track in Germany. The first round of closed-course vehicle subsystem testing was completed in Michigan with the following activities:

- Based on March 2020 preparations for this Subtask, IAV's TOSCo core team remotely, from Germany, instructed local IAV engineers to re-enable TOSCo vehicles and the mobile intelligent traffic light.
- Testing was performed with the CAMP Technical Management Team (TMT) in the lead with local and remote IAV support.
- Approximately 250 test runs were conducted over four and a half (4.5) days resulting in 160 GB of data. Data was made available to CAMP TMT and IAV for analysis.

During the second quarter of this report, the TOSCo Project Team carried out the following activities:

- The analysis of the test data collected during the September 2020 testing was completed.
- Based on the test results, the Project Team identified and resolved issues with the Coordinated Launch Performance of TOSCo vehicles just before the end of the year.
- The Project Team revised DSRC antenna models and mounting positions on IAV's MII and on one of the TOSCo vehicles to improve reception range. The new antenna provides the means to mount antennas (manufactured by MobileMark) directly onto glass surfaces.

- The TOSCo vehicle algorithm was revised as necessary towards the second round of vehicle testing scheduled for February 2021 as follows:
    - Transferred findings from the first round of testing into project tickets to make progress and improvements transparent to the Project Team.
    - Validated changes to vehicle software within the vehicle-level simulation environment using the latest detector-based infrastructure algorithm on a selected State Highway 105 intersection.
    - Introduced infrastructure algorithm improvements from Task 10 to vehicle software behind 9.3 focus.
    - Introduced "Risk Mitigation Strategy" for red light, non-queue scenarios previously identified as ASIL-D by the Task 12 functions safety analysis.

The following activities were conducted by the Project Team during the third quarter of this report:

- Finalized vehicle SW "Test_2_Rel2" and "Test_2_Rel3" and used it for February 2021 testing activities.
    - Added mixed traffic scenarios with unequipped vehicle(s) to exercise the object fusion function.
- Completed second round of vehicle testing at the FT Techno of America, Fowlerville Proving Ground in Michigan.
- The Team post-processed and analyzed test data collected during testing.
- Prepared and shipped vehicles to TTI for Task 11 testing activities at the RELLIS campus.
- Defined requirements towards engineering HMI to inform driver of CACC and TOSCo operation at deceleration limit of system.
- Prepared vehicle documentation in a user guide format for Task 11 activities.

This Subtask concluded April 30, 2021.

2.1.1.2 Additional TOSCo Prototype Vehicle Build(s) (Task 9.4)

This subtask concluded March 31, 2020.

Develop Portable OBEs (Task 9.5)

This Subtask has been completed. However, software updates will continue as needed. As a result of the continuation of the Subtask for software updates, the Project Team updated the OBE software to correct a bug related to MAP message generation.

Verify TTI Infrastructure Algorithm in Vehicle-level Simulation (Task 9.6)

This subtask concluded April 30, 2020.

Verify / Refine Combined Vehicle Software in Simulation (9.7)

The TOSCo Project Team took advantage of pandemic-induced schedule disruptions to utilize a revised vehicle-level simulation environment, modeling one intersection along the SH105 Corridor to exercise a version of the vehicle subsystem software that integrates the DENSO OBE software module, the IAV integrated vehicle controller and the TTI infrastructure algorithm. This represented the first time all elements were brought together in a vehicle-level simulation and offered the opportunity to thoroughly examine and refine subsystem software prior to actual on-road testing.

The Project Team completed all originally planned work under this subtask and has elected to keep the vehicle-level simulation active as it continues to provide valuable insight into TOSCo behavior as the vehicle algorithm and infrastructure elements continue to evolve, particularly queue length determination. These activities are not on the critical path.

The following activities were completed under this Subtask during the first quarter of this report:

- Updated the vehicle-level simulation intersection location to match a physical intersection along the SH105 Corridor in Conroe, Texas.
- Completed initial operation of the Texas intersection in vehicle-level simulation.
- Updated the detector-based infrastructure algorithm to account for logical queue growth.
- Investigated vehicle behavior and refined vehicle software based on results from closed-loop interaction with detector-based infrastructure algorithm.
- Developed experimental plan to evaluate the effects of varying queue length and impact of queue detector configuration on vehicle string performance.
- Performed baseline simulation sweep for TOSCo-vehicles only scenarios to verify integration of combined vehicle subsystem.
- Updated SimLinker to integrate the one-click switch between the BSM-based and detector-based infrastructure algorithms and between the Michigan and Texas intersection scenarios in vehicle-level simulation.
- Transferred updated software and parametrization / lessons learned to TOSCo vehicles prior to closed-track testing in Fowlerville, Michigan.

The following activities occurred during the second reporting period of this report:

- The TOSCo Project Team completed planned work to exercise a combined version of the vehicle subsystem software utilizing a revised vehicle-level simulation environment representing an intersection along the SH105 corridor in Texas which included:
  - DENSO OBE software
  - IAV's integrated vehicle controller
  - Detector-based infrastructure algorithm
- Enabled radar model in vehicle-level simulation to detect stationary targets as a result of an investigation on the behavior of the sensor used in TOSCo vehicles.

- Derived scenarios to demonstrate CACC and TOSCo system limits in vehicle-level simulation to be used as part of the driver training in the project in preparation for field testing in the next phase of the project.
- Performed baseline simulation sweeps and analyzed results for scenarios that include queues of non-equipped vehicles.
- Performed simulation sweeps and analyzed results for scenarios that included a non-equipped "stalled" vehicle, a vehicle turning into a driveway, and a vehicle turning out of driveway in front of the TOSCo string.

During the third quarter of this report, the Project Team performed a simulation study of varying closing speeds between the TOSCo string and braking vehicles to analyze the closing speed capability of a TOSCo string with respect to stopped and slowing vehicle(s). The Team also evaluated scenarios in vehicle-level simulation that challenges TOSCo vehicle capabilities to respond to various degrees of error in queue length estimation by the infrastructure. The result will be used to develop guidelines for infrastructure requirements and driver expectation.

During the final quarter of this report, the Project Team evaluated multiple "Risk Mitigation" strategies in vehicle-level simulation to help prepare trained drivers in identifying failure conditions during the corridor testing in order to take over control of the system. The team also performed simulation sweeps with increased initial CSTOP decelerations to better match the expectations of non-equipped surrounding vehicles during stopping scenarios. The results will be used to develop guidelines for infrastructure requirements and driver expectation.

Implement TOSCo In Infrastructure Components (Task 10)

The objectives for this task are to transfer the infrastructure control algorithms developed in Task 4 of the TOSCo Phase 1 Project from the simulation environment into representative infrastructure components. The infrastructure subsystem will be implemented in the hardware and verified in a controlled test environment in preparation for integration of the full system of the selected corridor.

Build Infrastructure Components (Task 10.1)

This subtask for concluded on December 31, 2019.

Implement TOSCo Functionality (Task 10.2)

During the first quarter of this report, the TOSCo Project Team completed the following activities:

- Refined and verified software elements of the infrastructure subsystem prior to resuming physical implementation.
- Revised green window computation algorithm to address lesson learned as part of field testing.
- Added robustness features and error check to queue detection algorithms.

This subtask was concluded on August 31, 2020.

Verify Infrastructure Subsystem(s) in Controlled Setting (Task 10.3)

This Subtask started in the first reporting quarter of this report with the TOSCo Project Team completing integration (bench) testing of all software components. The team initiated deployment of the TOSCo processor at the RELLIS Connected Intersection Testbed, configured detection zone in radar detection system, and worked to resolve software compatibility issues with generation of RTCM corrections using Conroe CORS station.

The Period of Performance end date of this subtask was extended to November 30, 2020 due to delays caused by the COVID-19 Pandemic.

During the second quarter of this report, the Project Team completed the following activities:

- Initiated software procurement for the generations of J2735 RTCM corrections using the Conroe CORS station.
- Conducted initial testing of the TOSCo infrastructure as follows:
    - Discovered errors in the SPaT message generated by the traffic signal controller during coordination.
    - Explored alternative solutions to address the error issues, including the following:
        - Deploying an external SPaT generator
        - Deploying a third-party vendor
        - Switching controller manufacturers
    - Initiated development of the external SPaT generator for the Siemen's controller.
    - Initiated development of the TOSCo SPaT message generator specific to the Siemen's controller.
    - Initiated testing of queue reporting accuracy of the data provided to TOSCo vehicles.

The redeployment of the TOSCo infrastructure elements consistent with the new FM 1960 corridor was completed by the Project Team during the third quarter. Verification testing of infrastructure components was completed as well as the assessment of queue reporting accuracy of data provided to TOSCo vehicles. The Project Team explored the potential to modify queue generation methodology to utilize direct measures of speeds and queue dissipation logic for more accurate green window estimation.

This Subtask concluded March 31, 2021.

Procure Corridor Hardware (Task 10.4)

This Subtask was initiated early to mitigate COVID-19 and potential important risks during the first quarter of this report. As a result, the team updated inventory of equipment needs, requested updates of quotes and delivery schedules.

During the second quarter of this report, the Project Team initiated contact with the vendor of DSRC units to confirm availability of devices for purchase and continued to work with the City of Conroe to refine estimate of equipment needs for deployment in the SH105 Corridor.

The Project Team conducted the following activities during the third quarter of this report:

- Conducted an inventory of equipment for new the TOSCo corridor with TxDOT.
- Issued purchase orders for deployment infrastructure components.
- Procured a strikable target for RELLIS testing.

Fourth quarter activities were conducted as follows:

- The Project Team completed procurement of infrastructure components.
- Prepared plans for deploying TOSCo infrastructure elements for FM 1960 corridor.
- Released bid for infrastructure deployment contractor.
- Completed infrastructure deployment schedule.
- Received all major infrastructure equipment for deployment at 14 intersections.

System Verification and Refinement (Task 11)

The objectives for this task are to complete work on progressively implementing TOSCo, first on a controlled test facility then on the SH 105 Corridor in Conroe, Texas. The work done in Phase 2a will include creating verification plans, executing the plans to verify TOSCo in a controlled setting, and refining the infrastructure algorithms as needed.

Implement TOSCo Functionality (Task 11.1)

This Subtask was extended to further refine the system verification plan. During the first reporting period of this report, the project team explored the use of a tailpipe emission sniffer to collect fuel / emissions data to support benefits assessment. The Project Team also initiated revisions to update verification plans, initiated planning for combined infrastructure and vehicle-level system verification testing at RELLIS, and investigated training options to fulfill SAE Driver Level 2 requirements.

During the third reporting quarter of this report, the Project Team completed the system verification test plans and completed the SAE Driver Level 2 Training.

The Subtask concluded April 31, 2021.

Verify System in Controlled Settings (Task 11.2)

This Subtask was scheduled to begin on May 1, 2020 but was retimed to start February 1, 2021. This Subtask commenced during the third quarter of this report. The Project Team completed the following activities:

- Performed mock test scenarios with TOSCo pods and infrastructure algorithm logging to ensure test procedures will work and data from infrastructure is accurate.

- Developed comprehensive test schedules for planned April 2021 testing.
- Shipped three TOSCo vehicles to RELLIS campus.

During the fourth quarter of this report, the Project Team completed the following:

- Established preparation, execution and post-processing processes for integration testing. The team synchronized vehicles and infrastructure logs with a unique naming scheme and leveraged the time difference between the US and Germany to minimize turn-around time for improvements.
- Completed three rounds of integration testing. The team employed scenario-based testing designed to replicate potential situations in corridor and conducted more than 230 test runs over a three-week period. The team then transitioned from fixed time signal control to actuated coordinated signal control. Most scenarios used vehicle entry speeds of 50 mph at 55 mph speed limit and time gaps down to 0.6 seconds without the presence of a queue. The team also ran scenarios with queues where TOSCo vehicles approached a queue of four unequipped vehicles waiting at the intersection.
- Completed ground-level collection of video for virtual demonstration scheduled for the end of August 2021.

This Subtask was scheduled to conclude April 30, 2021 but has been retimed to conclude July 31, 2021.

Refine Vehicle/Infrastructure Algorithms (Task 11.3)

This Subtask commenced during the third quarter of this report. The Project Team completed the following activities:

- Identified and conducted initial equipment inventory of the new field test corridor (FM 1960).
- Initiated development of MAPs for the new corridor.
- Initiated development of queue detection zones for the new test corridor.
- Developed deployment plans for queue detection system with TxDOT field personnel and equipment vendors.

During the fourth quarter of the report, the Project Team completed the following activities:

- Refined the vehicle algorithm and OBE software to account for behavior of production traffic light controllers and to allow transition from ‘fixed timing’ to ‘coordinated actuated’ control and correlating SPaT information.
- Modified vehicle subsystem parameters to better match naturalistic driving behavior and cause less disturbance to surrounding traffic while following TOSCo optimization criteria.
- Refined infrastructure data log for retaining evaluation data.
- Refined the queue detection algorithm to improve queue clearance estimation.

This Subtask was schedule to end April 30, 2021 but has been retimed to conclude June 30, 2021.

Performance Assessment (Task 12)

The objectives for this task are to establish and refine benefits estimates for the TOSCo system operation in simulated deployment scenarios based on data collected from prototype testing in Task 11. Analysis will begin with data from evaluations of system behavior in controlled settings, be progressively refined using data from corridor operational testing, and be completed with final estimation(s) based on system verification testing. Analysis will also inform refinement of the system hazard analysis from Phase 1 to reflect the final system configuration and performance data.

Establish Performance Analysis Plan (Task 12.1)

Although the milestone of preparing an initial performance assessment plan was met according to the schedule, this subtask remains open in order to incorporate periodic refinements to the plan, especially during subsystem integration testing that was delayed due to the COVID-19 Pandemic.

Update Corridor Simulation Models (Task 12.2)

During the first reporting period of this report, the Project Team initiated implementation of the TOSCo logic designed to operate independent from development software for the traffic-level simulation updates. The team completed initial integration of TOSCo libraries (vehicle control source code) into the traffic-level simulation driver model dll during the second quarter of this report.

The Project Team completed the following activities during the third quarter of this report:

- Tested and debugged TOSCo libraries in use for traffic-level simulations.
- Incorporated features into the TOSCo Driver Model to enable simulation with multiple intersections.
- Developed a script within the TOSCo Driver Model to calculate evaluation performance measures such as D\delay, travel time, etc.

The Project Team completed initiated development of the VISSIM model for FM 1960 during the fourth quarter of this report.

This subtask remains open in order to incorporate periodic refinements to the simulation models, especially during subsystem integration testing that was delayed due to the COVID-19 Pandemic.

Assess Potential Benefits (Task 12.3)

This Subtask was scheduled to start on May 1, 2020 but has been delayed due to the effects of the COVID-19 Pandemic and is now scheduled to end February 28, 2022.

During the final quarter of this report, the Project Team completed the benefits estimation report for SH105.

Update System Specification & Hazard Analysis (Task 12.4)

This Subtask was schedule to start on August 1, 2020 but the project team pulled the task forward and began work on March 1, 2020. During the first reporting period of this report, the project team completed integrating infrastructure elements into the fault tree and functional safety concept.

The Project Team initiated Phase 2 updates for the Functional Safety Report, Vehicle System Specification Report and the Infrastructure System Specification Report during the fourth quarter of this report.

3 Cooperative Automated Driving Systems

The objectives of this project were to facilitate collaboration and sharing of research results between Crash Avoidance Metrics Partners LLC (CAMP) Vehicle-to-Infrastructure 3 (V2I-3) Consortium, the United States Department of Transportation (USDOT) and other interested stakeholders to provide input to UDOT's cooperative automation research roadmap, to identify areas for potential collaboration and to begin the process of cooperatively developing and evaluating promising Cooperative Automated Driving Systems (CADS) technology, This effort supported the implementation of Connected Automated Vehicles (CAV) systems by engaging multiple OEM's, suppliers and Infrastructure Owner and Operators (IOOs) in the system definition process.

The project started on July 1, 2018 and concluded July 31, 2020.

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4 Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory / Warning (QA/QW) System

The purpose of the Event-Driven Configurable Messaging (EDCM) Design and Development and Work Zone Queue Advisory / Warning (QA/QW) System Project was to develop and implement an architecture to support flexible message scheme with the ability to dynamically adjust two-way data exchange between equipped vehicles and a Traffic Management Center (TMC).

The original project was divided into two phases. Phase I laid out the technical foundation for the EDCM concept by leading coordination and planning with the primary infrastructure partner, Virginia Department of Transportation (VDOT) with the aim of ensuring that final products would address a broad set of use cases for a wide variety of Infrastructure Owners and Operators (IOO) and Original Equipment Manufacturer (OEM) implementers. In addition, Phase I created a bench-test reference system including communication mechanisms and the functionality to demonstrate flow and processing of message to support the EDCM protocols.

Phase 2 of the project would have expanded Phase I by building the additional functionality required to support the general EDCM Concept of Operations (ConOps) and system requirements.

At the end of 2019, the USDOT elected to not fund Phase 2 of the EDCM Project, and the project was concluded at the end of Phase 1. EDCM Phase 1 concluded technical operations June 30, 2020 with project close out concluding December 31, 2020.

The final project briefing to USDOT/FHWA was conducted on July 16, 2020. The following four reports documenting the EDCM Phase 1 were developed and posted on the CAMP website. Links to download the reports were provided to FHWA.

1. Event Driven Configurable Messaging (EDCM) Concept of Operations – Version 1.6

2. Queue Advisory & Queue Warning (QA/QW) System and In-vehicle Application Requirements

3. Event Driven Configurable Messaging (EDCM) Phase 1

4. Event Drive Configurable Messaging (EDCM) XML Schema

The TMT reviewed and provided comments to the CV PFS companion project on V2I Queue Advisory/Warning Applications: Concept and Design.

5 Stakeholder Engagement and Outreach Project

This project addresses the continued need for Vehicle-to-Infrastructure (V2I) deployment support beyond the current and future proposed Federal Highway Association (FHWA) and Crash Avoidance Metrics Partners LLC (CAMP) V2I Projects. The objectives of the project are for the continued facilitation, collaboration and support with a broad range of stakeholders and partners as necessary to implement the results of the V2I projects and identify additional needs.

IOO/OEM Forum Outreach (Task 2)

Beyond what is currently provided through other FHWA/CAMP project work orders, CAMP will provide support to the Infrastructure Owners and Owners (IOO/OEMs), including state and location Departments of Transportations (DOTs), through mechanisms like the IOO/OEM Forum and Connected Vehicle Pooled Fund Study (CV PFS) for implementation and verification support of infrastructure-side connected vehicle system elements.

Reduced Speed / Work Zone Warning Working Group

During the period of performance for this report, the working group continued to monitor ongoing smart work zone initiatives and share information across activities, including those in Michigan, Texas, Arizona, Virginia and the FHWA Work Zone Data Initiative (WZDI). Specific accomplishments included:

First Quarter:

- The Mapping Tool Chain was embedded in FHWA Work Zone Data Collection (WZDC) Tool providing both RSMs for local broadcast and WZDI compliant data.
- “Encouraging use of Work Zone Mapping Tools – Request for IOOs” document developed and presented at the Cooperative Automated Transportation (CAT) Coalition Strategic Initiatives Webinar on July 23, 2020 along with a WZDC tool overview provided by FHWA.
- Monitored implementation to collect lessons learned from testing in Texas, Arizona and California.
- Encouraged coordination between WZDI v3.0 and SAE J2945/4 Roadside Safety Message (RSM) standards activities.

Second Quarter:

- Reviewed connected work zone testing experience in Florida and Virginia.
- Limited field experience to date caused a shift in focus from a formal Lessons Learned Document to a presentation format summary of implementation experiences that includes gaps identified for future refinement of the tools and processes (technical and business).

- Continued outreach activities including a presentation to the Connected Vehicle Pooled Fund Study (CV PFS) promoting use of the WZDC Tool ('The Ask') in October 2020.
- Continued encouraging coordination between WZDI v3.0+ and SAE J2945/4 Roadside Safety Message (RSM) standards activities.

Third Quarter:

- Developed outreach material to promote additional field deployments of connected work zones.
- Developed a white paper describing levels of work zone data and supported functionality to encourage coordination of WZDI and SAE J2945/4 standards initiatives.

Fourth Quarter:

- Revised white paper describing levels of work zone data and supported functionality to encourage coordination of WZDI and SAE J2945/4 standards initiatives to incorporate feedback from Volpe.
- Developed summary presentation on "Connected Work Zones: Lessons Learned Thus Far" in lieu of white paper capturing work in Arizona and Texas. Awaiting input from California and Virginia.
- Developed draft "Enabling Connected Work Zones: Needs and Next Steps" document for use post CAT Coalition.

Signal Phase and Timing (SPaT)/Red Light Violation Warning (RLVW) Working Group

V2I Consortium Participants continued to participate in the ongoing monthly webinars for the Signal Phase and Timing / Red Light Violation Warning (SPaT/RLVW) Working Group.

During the first reporting period of this report, the working group continued to refine the concept paper containing seven primary actions on Enabling Connected Interactions, developed a matrix of activities containing approach outcomes, and external efforts to coordinate with other parallel activities led by USDOT/ITE projects. Additionally, the working group continued to update and refine the five-phase testing and verification approach for enabling connected intersections for deployment readiness to complete ongoing verification. Continued development of a draft document entitled "Connected Intersection Overall Testing Approach." The document was reviewed by several IOOs.

The working group continued in the second quarter to refine the concept paper containing seven primary actions on Enabling Connected Intersections, developed a matrix of activities containing approach outcomes, and external efforts to coordinate with other parallel activities led by USDOT/ITE projects and the CAMP, UMTRI and CV PFS project on Connected Signalized Intersection Verification (CSIV/CIP). Additionally, the working group continued to update and refine the five-phase testing and verification approach for enabling connected intersections for deployment readiness to complete ongoing verification. Discussion continued on the development of field verification toolset for SPaT, MAP and RTCM over-the-air messages being developed by CAMP under the CSIV/CIP Project. Development continued on the draft document entitled "Connected Intersection Overall Testing Approach."

During the third quarter of the performance period of this report, the working group continued to refine the concept paper containing seven primary actions on Enabling Connected Intersections, developed

a matrix of activities containing approach outcomes, and external efforts to coordinate with other parallel activities led by USDOT/ITE projects and the CAMP, UMTRI and CV PFS Project on Connected Signalized Intersection Verification (CSIV/CIP). Additionally, the working group continued to update and refine the five-phase testing and verification approach for enabling connected intersections for deployment readiness to complete ongoing verification. The draft document was revised based on the ITE Connected Intersection Project field verification process and findings from field tests conducted in Ann Arbor, Michigan in the CAMP/CSIV/CIP Project. Continued the development and refinement of a draft document entitled “Connected Intersection Overall Testing Approach.” Discussion and development of a draft document on Consistent Procedures for Operations (CPO) commenced to address connected intersections operations approach. There is a need to clarify operational approaches to several scenarios that will regularly or periodically occur with operational Connected Intersections.

During the fourth quarter of the performance period of this report, the working group continued to refine the concept paper containing seven primary actions on Enabling Connected Intersections, developed a matrix of active containing approach outcomes, and external efforts to coordinate with other parallel activities led by USDOT/ITE projects and the CAMP, UMTRI and CV PFS Project on Connected Signalized Intersection Verification (CSIV/CIP). Additionally, the working group continued to update and refine the five-phase testing and verification approach for enabling connected intersections for deployment readiness to complete ongoing verification. The draft document is revised based on the ITE Connected Intersection Project field verification process and field test data from 11 sites and findings from field tests analysis including conducted tests in Ann Arbor, Michigan in the CAMP/CSIV/CIP Project. Continued the development and refinement of a draft document entitled “Connected Intersection Overall Testing Approach.” The document is being reviewed by several IOOs.

A need exits to equip a corridor with RLVW capabilities for a ‘basic’ RLVW warning application that would allow OEMs to test their pre-production RLVW applications based on yellow and red interval indications (i.e., not relying on data describing green interval end times). Discussion continued on what would it take to validate a corridor for testing pre-production basic RLVW application.

Connected Automation Working Group

During the reporting periods for this report, the TOSCo PI continued to meet with the IOO/OEM Forum Connected Automation Working Group to present the TOSCo Project information and obtain feedback.

Support for Standards Development (Task 3)

In addition to the support currently provided under other FHWA/CAMP projects, CAMP provided support and contribution to standards development organizations such as the Society of Automotive Engineers (SAE) for automotive-related as well as the Institute of Transportation Engineers (ITE) and AASHTO for infrastructure-related standards development. An example of this continued support is the ongoing development of the SAE J2945/4 RSM which is needed to support the deployment of infrastructure messages enabled in-vehicle in RSZW and QA/QW developed under the Vehicle-to-Infrastructure Safety Applications (V2I-SA) Project.

During the first quarter of this report, the SAE activity consisted of the following:

- In the Infrastructure Applications Technical Committee (IATC), Purser Sturgeon conducted requirements and Needs to the Requirement Traceability Matrix for J2945/4 (Roadside Safety Message).
- Work continued to define user needs and mapping layer architecture for J2945/A – Next generation mapping for connected Vehicle-to-Everything (V2X) applications.
- Presented ITE Connected Intersection (CI) update at the IATC meeting in support of J2945/B (Recommended Practices for Connected Signalized Intersection Applications). Focus was on the RLVW application testing needs.
- CAMP provided EDCM Phase 1 documents for query messaging and response for V2X application to SAE IATC document sponsor for J2945/C (Traffic Probe Use and Operation) for system design.
- Conducted a walkthrough of J2945/C system design.

Coordination continued between Applications Testing for Interoperability Task Force in IATC and the USODOT/ITE CI Project Testing and Conformity Task Force. The following are USDOT/ITE projects activities:

- Roadside Unit (RSU) Standardization – User needs, requirements and NRTM were completed. The work progress began for system design and is scheduled to be completed by November 16, 2020 and the design document walkthrough is scheduled for December 3, 2020.
- Connected Intersection (CI) – Completed the ConOps user needs. Work in progress for requirements development which is scheduled to be completed in December 2020. Draft version of CAMP-developed RLVW ConOps was shared with the CI Project team for review and comments.

During the second quarter of the period of performance of this report, the following activities were conducted:

- The Infrastructure Applications Technical Committee (IATC) completed the following:
    - The document ballot ended on December 20, 2020 for the SAE J2945/4 Road Safety Message.
    - Document ballot progress initiated for the SAE J2945/C Vehicle Probe Data and Use. Completion date is January 14, 2021.
    - Development of user needs and architecture to define messages consisting of layers that define static (base geometry), dynamic (temporary) geometry and associated attributes for infrastructure maps is in progress for Next Gen Mapping for Connected V2X Application (J2945/A).
    - Coordination continued between Applications Testing for Interoperability Task Force in IATC and the USDOT/ITE CI Project Testing and Conformity Task Force.
- The USDOT/ITE project completed the following activities:
    - The System Design Document walkthrough for the RSU Standardization was conducted from December 1 through December 3, 2020.

  - The Requirements Document for the Connected Intersection (CI) Project walkthrough was conducted on December 7 through December 10, 2020. The System Design Document completion is scheduled for March 2021. Draft version of the CAMP-developed RLVW ConOps and requirements documents were shared with the CI Project team for review and comment.

During the third quarter of the period of performance of this report, the following activities were conducted:

- The Infrastructure Applications Technical Committee (IATC) completed the following:
  - The document ballot ended on December 20, 2020 for the SAE J2945/4 Road Safety Message. The comment resolution progress began.
  - The document ballot ended on January 14, 2021 for the SAE J2945/C Vehicle Probe Data and Use. The comment resolution was also completed, and the second ballot was planned.
  - Development of user needs and architecture to define messages consisting of layers that define static (base geometry), dynamic (temporary) geometry and associated attributes for infrastructure maps was still in progress for Next Gen Mapping for Connected V2X Application (J2945/A).
    - Draft versions of the user needs and layered architecture document was in progress to address mapping scalability for current and future applications. A Stakeholder walkthrough of the ConOps was being planned.
  - Coordination continued between Applications Testing for Interoperability Task Force in IATC and the USDOT/ITE CI Project Testing and Conformity Task Force.
- The USDOT/ITE project completed the following activities:
  - The System Design Detail Document walkthrough for the Connected Intersection Project was conducted on March 8 through March 11, 2021.
  - Fifteen agencies responded to the solicitation of interest for verifying needs, requirements and design as specified in the CI Implementation Guide. Due to limited resources and time, four agencies were selected for field test and verification. Requirements for self-test and verifications were provided to the other 11 agencies.

During the fourth quarter of the period of performance of this report, the following activities were conducted:

- The 28-day ballot ended on May 10, 2021 for the SAE J2945/4 Road Safety Message. It was approved by 68.6%.
- The document ballot ended on January 14, 2021 for the SAE J2945/C Vehicle Probe Data and Use. Comment resolution was completed, and a second ballot was in progress through April 26, 2021. The committed approved by 88.9%.
- Development of user needs and architecture to define messages consisting of layers that define static (base geometry), dynamic (temporary) geometry and associated attributes for infrastructure maps is still in progress for Next Gen Mapping for Connected V2X Application (J2945/A).
- Conducted ConOps Stakeholder Review Meeting on May 17 and May 18.

- ASN.1 Object definitions were in progress.
- Coordination continued between Applications Testing for the Interoperability Task Force in IATC and the USDOT/ITE CI Project and Conformity Task Force.

The USDOT/ITE project completed the following activities:

- The RSU Standard Draft (V01) was published on the ITE website.
- The System Design Details (SDD) for the Connected Intersections (CI) implementation Guide (Draft V1.09) was reviewed by the field verification participating organizations.

  Fifteen sites from 13 participating organizations are providing intersection field test data for analysis and validation of SPaT and MAP messages as per the CI Implementation Guide for RLVS. Participating organizations will continue to collect field test data for validation through the end of July 2021 for analysis and verification.

Support for Other Stakeholders (Task 4)

CAMP, as mutually agreed to with FHWA, will provide support (not-covered in other FHWA/CAMP projects) to additional stakeholders / partners identified as key to the successful widespread deployment and verification of the infrastructure-side elements of CV safety and mobility systems.

Throughout the Period of Performance of this report, CAMP has provided support/participation in the following Taskforces under the ITE Project:

- Controller Issues Taskforce
- SPaT/MAP Taskforce
- Testing and Conformity Taskforce

APPENDIX A. List of Acronyms

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
ACC	Adaptive Cruise Control
ADTF	Automotive Data and Time-Triggered Framework
AERIS	Applications for the Environment: Real-Time Information Synthesis
AMCD	Advanced Messaging Concept Development
BOQ	Back of Queue
CACC	Cooperative Adaptive Cruise Control
CACC-SST	Cooperative Adaptive Cruise Control – Small-scale Test (Project)
CADS	Cooperative Automated Driving Systems
CAMP	Crash Avoidance Metrics Partners LLC
CARMA	Cooperative Automation Research Mobility Application
CAV	Connected Automated Vehicle
CCI	Clarifications for Consistent Implementations
CMC	Consortium Management Committee
ConOps	Concept of Operations
CORS	Continuously Operating Reference Station
CSW	Curve Speed Warning
CV	Connected Vehicle
CVIR	Connected Vehicle-Infrastructure Research
CVPFS	Connected Vehicle Pooled Fund Study
DLL	Dynamic Link Library
DOT	Department of Transportation
DQR	Data Query Response
DSRC	Dedicated Short-Range Communications

Acronym	Definition
EDCM	Event Driven Configurable Messaging Design & Development and Work Zone Queue Advisory / Queue Warning (QA/QW) Project
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FSC	Functional Safety Concept
HARA	Hazard Analysis / Risk Assessment
HMI	Human-machine Interface
I2V	Infrastructure-to-Vehicle
IA	Infrastructure Applications
IEEE	Institute of Electrical and Electronics Engineers
IFM	Improved Freeway Mobility
IHP	Integrated Highway Prototype
IOOs	Infrastructure Owners and Operators
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
MAP	SAE J2735 Map Message
MDOT	Michigan Department of Transportation
NOCoE	National Operations Center of Excellence
OBE	On-board Equipment
OEMs	Original Equipment Manufacturers
ORAD	On Road Automated Driving
PFS	Pooled Fund Study
PI	Principal Investigator
PoC	Proof-of-Concept
POP	Period of Performance
QA/QW	Queue Advisory / Queue Warning

Acronym	Definition
QM	Query Message
QR	Query Response
RLVW	Red Light Violation Warning
RSE	Roadside Equipment
RSM	Roadside Safety Message
RSU	Roadside Unit
RSZW	Reduced Speed/Work Zone Warning
RSZW/LC	Reduced Speed Zone Warning / Lane Closure
RTCM	Radio Technical Commission for Maritime Services
RWMP	Road Weather Management Program
SAE	SAE International
SH	State Highway
SOQ	State of Queue
SPaT	Signal Phase and Timing
SSGA	Stop Sign Gap Assistance
STOL	Saxton Transportation Operations Laboratory
SWIW	Spot Weather Impact Warning
TC	Technical Committee
TMC	Traffic Management Center
TMT	Technical Management Team
TOSCo	Traffic Optimization for Signalized Corridors (Project)
TSA	Traffic Applications Signal
TSMO	Transportation System Management and Operations
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UCR	University of California Riverside

Acronym	Definition
UMTRI	University of Michigan Transportation Research Institute
UPER	Unaligned Packed Encoding Rules
USDOT	United States Department of Transportation
Utah DOT	Utah Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I-2	Vehicle-to-Infrastructure 2 Consortium
V2I-3	Vehicle-to-Infrastructure 3 Consortium
V2I/I2V	Vehicle-to-Infrastructure / Infrastructure-to-Vehicle
V2I-SA	Vehicle-to-Infrastructure Safety Applications (Project)
V2X	Vehicle-to-Everything
VDOT	Virginia Department of Transportation
VISSIM	Verkehr In Städten – SIMulationsmodell (from German, a Traffic Flow Simulation Package)
VTTI	Virginia Tech Transportation Institute
WIP	Work In Progress
WSU	Wireless Safety Unit
WZ	Work Zone
WZDI	Work Zone Data Initiative
XML	eXtensible Markup Language

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