Development of Vehicle-to-Infrastructure Applications Program

Sixth Annual Report

July 1, 2019 through June 30, 2020

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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 sixth 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, Mazda, Nissan, Subaru, Toyota and VW/Audi. The period covered by the report is from July 1, 2019 through June 30, 2020. 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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CAMP, Vehicle-to-Infrastructure (V2I), safety, Cooperative Adaptive Cruise Control (CACC), eco-approach, eco-departure, sustainability, mobility, vehicle control, automation, stakeholder, outreach, TOSCo, work zone	

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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 sixth year of program operation. The period covered by the report is from July 1, 2019 through June 30, 2020. 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 sixth 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 and Shulman and Geisler, 2019, No. FHWA-JPO-19-780.)

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 the Federal Highway Administration (FHWA) and the 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) and Volvo (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, Mazda, Nissan, Subaru and VW/Audi. (Note: Mazda and Subaru elected to withdraw from the V2I Consortium at the end of 2019). This Consortium represents a broad 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
- Administered the following active projects during this annual reporting period:
  - Cooperative Automated Driving System (CADS) 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 – **ongoing**
  - 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, Mazda, Nissan, Subaru and VW/Audi) (Note: Mazda and Subaru elected to withdraw from the V2I Consortium at the end of 2019)

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)

Cooperative Automated Driving Systems (CADS)

Project Status: In Progress

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

Project Timeline: July 2018 – July 30, 2020

The objectives of this project are 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 supports 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: Awarded May 2019

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 is 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 are 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 Data Query Message (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 on 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 Query Message (QM) and Response Message (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

Stakeholder Engagement and Outreach

Project Status: Awarded March 2019

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: 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
- 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 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 Infrastructure Application (IA) Technical Committee (TC) to discuss map data needs to support in-vehicle applications
    - Engaged the FHWA Vehicle-to-Everything (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 focusing on development of functional safety, test procedures and test tool

- 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

1 V2I Program Administration

This document presents the Sixth 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, 2019 through June 30, 2020. 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, Mazda, Nissan and Subaru, VW/Audi. (note: Mazda and Subaru elected to withdraw from the V2I Consortium at the end of 2019.) 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 broad range of automotive perspectives from manufacturers as well as global viewpoints that encompass the U.S., Europe, and Asia. The Consortium Management Committees (CMC) meet on a monthly 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 I: Modeling and Analysis – Technical Period of Performance completed June 2019
- Traffic Optimization for Signalized Corridors (TOSCo) Project Phase 2: System Build and Test
- Cooperative Automated Driving Systems (CADS) Project
- Stakeholder Engagement and Outreach Project –
- Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (QA/QW) System Project

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.

1.1 Program Administration

The following deliverables were prepared and submitted to FHWA as part of the work completed during the past year:

- Quarterly Status Reports, summarizing progress in active projects within the V2I Program by calendar quarter. The Quarterly Status Reports were submitted to FHWA on July 30, 2019, October 30, 2019, January 30, 2020 and April 30, 2020.

- Quarterly Progress Briefings, providing a presentation to FHWA of the work performed in the preceding quarter. Quarterly Progress Briefings were completed on July 30, 2019, October 30, 2019, January 22, 2020 and April 20, 2020.

- 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.

- The Fifth Annual Report for the V2I Program (Shulman and Geisler, 2019, Report No. FHWA-JPO-19-780)

- Prepared and submitted the Annual Personal Property Inventory on November 7, 2019

- Prepared and submitted the Annual Equipment Inventory on November 7, 2019

- Conducted the CY2020 Annual Budget Review and Program Plan on November 7, 2019

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 and Shulman and Geisler, 2019, Report No. FHWA-JPO-19-780).

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.

2.1 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.

2.1.1 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.

2.1.2 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.

2.1.3 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.

2.2 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.

2.2.1 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. T

2.2.2 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.

2.3 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.

2.3.1 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) 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.

2.3.2 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.

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

During the first reporting quarter for this report, the project team met with key members of the IOO/OEM Forum Connected Automation Group at the monthly meetings in July and September. As a result of this technical exchange, the project team decided to move BOQ, Green Window Start, End elements into the SPaT message rather than employ a TOSCo Approach Container in the Roadside Safety Message (RSM). The project team also met with the City of Conroe and the Houston District of the Texas Department of Transportation (TxDOT) to brief both organizations of the Phase 2 award.

During the second reporting quarter for this report, the project team met with key members of the IOO/OEM Forum Connected Automation Group at the monthly meetings in October, November and December and shared an initial performance assessment plan. The project team also presented CACC test results to the SAE Vehicle Applications Technical Committee in October 2019 in Columbus, Ohio. At the Institute of Electrical and Electronics Engineers' (IEEE) Vehicular Networking Conference in December 2019 in Los Angeles, California, the project team presented a paper titled "Optimizing Vehicle Approach Strategies for Connected Signalized Intersections."

The project team met with key members of the IOO/OEM Forum Connected Automation Group at the monthly meetings in January and March during the third reporting quarter for this report. At the March IOO/OEM Forum Connected Automation Group meeting, there was significant interest among the IOOs to leverage the portable OBEs that the project team assembled for use in evaluating RSUs installed along the SPaT Challenge Corridors. In response to this interest, the project team prepared documentation describing the portable OBE functions, operating requirements and limitations and

distributed it among the IOOs. During this quarter, the project team also attended the IOO/OEM Forum meeting in Washington DC on February 27, 2020 and conducted a PTV Talks Webinar for the PTV Group (manufacturer of the VISSIM Simulation Software) at the request of the manufacturer on February 27, 2020.

During the final reporting quarter for this report, the project team met with key members of IOO/OEM Forum Connected Automation Group at the monthly meetings in April, May and June. The focus of the discussion continued to be on the portable OBEs developed for use in TOSCo testing. On June 15, 2020, the project team presented a TOSCo overview within the context of interaction with the IOO/OEM Forum Connected Vehicle Working Group to the American Association of State Highway Transportation Officials (AASHTO) Committee.

2.3.3 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 to 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.

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

Subtask 9.1 initiated with the project team's development of the SPaT to include BOQ and a TOSCo-specific regional extension for Green Window Start and End times. The project team chose to replace the originally planned RSM with capabilities provided in the SPaT message as a means to improve efficiency by reducing messaging requirements. The project team also specified the form of the TOSCo Approach Container as the interface between the Denso Wireless Safety Unit (WSU) and the CarPC which hosts the TOSCo algorithm. The WSU was developed to be responsible for map matching and assembly of the TOSCo Approach Container. The project team also began integrating the Denso software contribution into the vehicle-level simulation. The result of this will add value by allowing testing of core software components using the TOSCo Phase 1 simulation scenarios prior to road testing.

During the second reporting quarter this report, the project team continued verification of the functionality of the SPaT regional extension in vehicle simulation and also continued verification of the Denso software's capability to provide the TOSCo Approach Container as required by the TOSCo algorithm.

In the third reporting quarter of this report, the project team completed verification of the SPaT regional extension in vehicle simulation as well as verification of the Denso software contribution that provides the TOSCo Approach Container as required by the TOSCo algorithm. The project team also completed adapting the software component in accordance with simulation results. This task was completed in the third quarter of this report.

2.3.3.2 Upgrade CACC Vehicles to TOSCo Capability (Task 9.2)

During the first reporting quarter for this report, the project team investigated the applicability of previous CACC vehicles to execute the TOSCo algorithm with focus on Coordinated Stop, Stopped, Creep and Coordinated Launch operating modes. As a result, the project team modified the vehicle

hardware architecture to satisfy TOSCo needs. The project team also improved time synchronization to correct inconsistencies between OBE time and CarPC time that were observed during previous CACC testing.

The existing CACC-equipped Hyundai Sonata was evaluated by the project team and it was determined that the vehicle will support full TOSCo capability during the second reporting quarter for this report. The team then upgraded both the Sonata and Cadillac Escalade CACC Vehicles for TOSCo implementation. The project team then upgraded and aligned the BOSCH forward detection radars, checked and released CAN gateway vehicle software, checked and released the Longitudinal Control vehicle software and tested vehicle (Automotive Data and Time Triggered Framework (ADTF) and V2X) ACC, CACC and TOSCo software. A new, more accurate time synchronization was successfully tested by the project team in an actual vehicle, and the team also completed the design of an Engineering / Assessment-level human-machine interface (HMI) for use in the TOSCo-equipped vehicles. An analysis of the 2018 test data was conducted, and possible changes were identified for improving the object fusion algorithm.

The project team completed the vehicle builds and prepared the documentation associated with the build including reference guides, vehicle user manuals and hardware architecture during the third quarter. The CAN Gateway bugs were fixed by the project team. The project team also tuned the MicroAutobox Longitudinal Control Software, integrated the TOSCo vehicle software ADTF binaries and configurations), and implemented a TOSCo engineering-level HMI based on a design approved by the project team. The HMI also includes a TOSCo Debug Graphical User Interface (GUI) showing host vehicle and speed profile information. The object fusion algorithm was improved by the project team and is ready for testing in a controlled environment. This Subtask closed during this quarter.

2.3.3.3 Verify Vehicle Subsystem in Controlled Setting (Task 9.3)

This Subtask commenced during the third reporting quarter of this report. The project team began by identifying a controlled access test facility suitable for verifying TOSCo vehicle performance and defined a vehicle subsystem verification plan for repeatability of test case execution. The project team plans to use IAV's Mobile Intelligent Infrastructure (MII) and trigger traffic light states by Dedicated Short-range Communication (DSRC) messages to implement an experimental intersection configuration broadcasting SPaT and SAE 2735 Map Message (MAP). The project team also verified the functionality of the TOSCo engineering-level HMI and debug HMI in all vehicles and refined the behavior of Denso OBE software for TOSCo Approach Container generation.

During the fourth quarter of the reporting period of this report, the project team developed a contingency plan to address time lost due to the COVID-19 Pandemic and conducted limited vehicle-level testing at the IAV facility in Germany in preparation for eventual testing in the US. The testing was scheduled for August and September but is delayed to September and October due to restrictions on international travel resulting from the COVID-19 Pandemic.

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

The project team ensured the applicability of two new candidate vehicles to operate the TOSCo algorithm with focus on Coordinated Stop, Stopped, Creep and Coordinated Launch Operating Modes and proceeded to procure the additional VW vehicles (Jetta and Tiguan) during the first reporting period of this report.

During the second reporting period of this report, the project team equipped production VW Jetta and VW Tiguan vehicles with CACC capability, measurement equipment, installed and aligned the BOSCH forward object detection radars, checked and released CAN gateway vehicle software, checked and released the Longitudinal Control Vehicle software, and tested vehicle (ADTF and V2X) ACC, CACC and TOSCo software.

During the third quarter period of this report, project team completed the vehicle builds and prepared the documentation associated with the builds including reference guides, vehicle user manuals and hardware architecture. The team also fixed CAN Gateway bugs and tuned the MicroAutobox Longitudinal Control software, integrated the TOSCo vehicle software (ADTF binaries and configurations) and implemented a TOSCo engineer-level HMI based on a design approved by the project team The HMI also includes a TOSCo Debug GUI showing host vehicle and speed profile information. The Subtask closed during this reporting period.

2.3.3.5 Develop Portable OBEs (Task 9.5)

The project team obtained all necessary hardware and built ten portable OBEs. This Subtask was completed in the second quarter of the reporting period of this report. However, software updates will continue as needed.

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

The project team initiated activity to develop the ability to operate the vehicle-level simulation with either the University of Michigan Transportation Research Institute (UMTRI) or TTI infrastructure algorithm. During the first quarter of the reporting period of this report, the project team also identified three data sources going into the UMTRI infrastructure component and Simulink computer that need to be replicated in the TTI algorithm for a clean transfer of the algorithm and began coding the interface for passing data between vehicle-level simulation computers.

During the second quarter of the reporting period of this report, the project team established communication between the infrastructure algorithm and vehicle-level simulation. TTI is now observing similar behavior to that of the UMTRI vehicle-level simulation.

Communication was established between the infrastructure algorithm and vehicle-level simulation during the third quarter of the reporting period. TTI continued to observe similar behavior to that of the UMTRI vehicle-level simulation.

During the fourth quarter of the reporting period of this report, the project team integrated TTI's detector-based SPaT regional extension generation VISSIM software module into UMTRI's vehicle-level simulation and verified proper data exchange and TOSCo vehicle string operation. This Subtask closed during this quarter.

2.3.3.7 Verify / Refine Combined Vehicle Software in Simulation (9.7)

During the fourth reporting period of this report, the project team adapted to the COVID-19 Pandemic-induced schedule disruptions to utilize a revised vehicle-level simulation environment, modeling one intersection along the SH 105 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 following activities were completed under this Subtask:

- Completed a full parameter sweep of vehicle-level simulation after integrating the Denso OBE software
- Integrated the IAV vehicle controller into the UMTRI simulation environment
- Integrated the TTI infrastructure algorithm in the UMTRI vehicle-level simulation
- Initiated a baseline simulation sweep of the UMTRI simulation environment
- Initiated modeling of the chosen SH 105 Corridor intersection in vehicle-level simulation
- Generated SPaT and MAP messages per TOSCo specification for the SH 105 Corridor
- Initiated developing definitions for simulation scenarios for the chosen intersection in vehicle-level simulation
- Initiated operation of chose corridor intersection in vehicle-level simulation

2.3.4 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.

2.3.4.1 Build Infrastructure Components (Task 10.1)

During the first quarter of the reporting period of this report, the project team investigated hardware and software procurement specifications for the RSUs and queue detection system. The encoding began by the project team for the SPaT message regional extension to include TOSCo elements from the traffic controller as well as providing sample SPaT and MAP messages from specific intersections on State Highway 105 to Denso in which to test vehicle-side software. The team also worked to gain access to the local Continuously Operating Reference Station (CORS) in Conroe, Texas of which TTI has a license that may be leveraged.

During the second quarter of the reporting period of this report, the project team identified controller hardware (Siemens) for deployment on the SH105 Corridor and repositioned existing queue detection equipment (Iteris) at a chose intersection.

During the third quarter of the reporting period of this report, the project team completed configuring a queue detection system and developed and uploaded a test timing plan into a traffic signal controller at the RELLIS intersection. A TOSCo infrastructure processor, which houses TOSCo infrastructure software module, was procured and configured by the team. Due to Federal Communications

Commission's (FCC) moratorium on new licenses for RSUs, the RSU installed at the RELLIS intersection will be reconfigured to operate on Channel 180 because the moratorium does not affect the new RUS licenses broadcast on this channel. The Subtask is completed.

2.3.4.2 Implement TOSCo Functionality (Task 10.2)

In starting this Subtask, the project team began by developing SPaT to include BOQ- and TOSCo-specific regional extension for Green Window Start and End time. This development continued into the second reporting quarter of this report. The team also continued to implement TOSCo infrastructure algorithms in representative component sets and captured SPaT messages under semi-actuated and uncoordinated signal controller operating modes.

During the third reporting quarter of this report, the team completed development of the Queue Estimation, Green Window Prediction, and Enhance SPaT message generation subsystems. The team also completed the installation of TOSCo Infrastructure subsystems on the TOSCo Infrastructure Processor as well we completing testing and data transfer between software components.

A site license was secured to access the TxDOT CORS station in Conroe, Texas and is 50% complete on the deployment of the Radio Technical Commission for Maritime (RTCM) Generation Process due to software issues with establishing connection to the Conroe CORS station. The project team reconfigured the RELLIS intersection RSU to broadcast on Channel 180 and reworked MAP data elements based on high-resolution reference point at the RELLIS intersection.

During the fourth reporting quarter of this report, the project team completed installation of the TOSCo Infrastructure software onto the TOSCo infrastructure computers, reworked MAP data elements based on a high-resolution reference point at the RELLIS test Intersection and completed testing and data transfer between software components. However, delays were encountered with installation and testing of the TOSC infrastructure processor and communications testing due to the COVID-19 Pandemic. The project team was able to work with Denso to successfully generate RTCM correction messages at CAMP and IAV. Work continued toward deploying the same RTCM generation subsystem being used in Germany and Michigan for field tests being conducted in Texas. During this quarter, the project team also initiated a simulation study to develop queue detection zone implementation guidance.

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

This Subtask started in the third reporting quarter of this report with the project team identifying and securing the use of a controlled access test facility in Texas suitable for verifying TOSCo infrastructure component performance. In the fourth report quarter of this report, the project team developed a contingency plan to address time lost due to the COVID-19 Pandemic, defined an initial verification plan for testing the infrastructure subsystem at the RELLIS Campus and initiated testing of portable OBEs to verify reception of enhanced SPaT, MAP and RTCM messages at the test site.

2.3.4.4 Procure Corridor Hardware (Task 10.4)

This Subtask was scheduled to start on June 1, 2020 but is delayed due to the COVID-19 Pandemic and is now projected to start on October 1, 2020.

2.3.5 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.

2.3.5.1 Implement TOSCo Functionality (Task 11.1)

This Subtask began in the third reporting quarter of this report with the project team developing test plan(s) for the Texas corridor for use on controlled access test facilities using trained drivers to verify the following:

- Proper data exchange between infrastructure and vehicle subsystems
- Intended subsystem behavior for all operating modes defined in the TOSCo System Specification.

The project team also developed the data collection capabilities necessary to support benefits assessment.

The following activities were carried out in the fourth reporting quarter of this report:

- The project team prepared a preliminary system verification plan for field studies to be performed in the SH 105 Corridor.
- The project team completed test plan(s) for the Texas Corridor for use on controlled access test facilities using trained drivers
- The project team identified data collection capabilities necessary to support benefits assessment, particularly with regard to emissions measurements

2.3.5.2 Verify System in Controlled Setting (Task 11.2)

This Subtask was scheduled to begin on May 1, 2020 but has been retimed to start December 1, 2020.

2.3.6 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.

2.3.6.1 Establish Performance Analysis Plan (Task 12.1)

The project team began this Subtask by defining Phase 2 traffic-level simulation objectives and the scenarios to employ in pursuing them. The project team also identified eight initial key performance-related questions and associated performance indicators.

During the second reporting quarter for this report, the project team pulled this task forward, completed an initial performance assessment plan and reviewed the plan with FHWA representatives during Review Meeting 6.5.

The project team shared the TOSCo performance assessment plan with the IOO/OEM Forum during the third reporting quarter for this report. The project team will continue this work past the original competition date to continue improving the plan since it is not on the critical path and extending the duration will not impact cost.

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

2.3.6.2 Update Corridor Simulation Models (Task 12.2)

This Subtask was pulled forward during the second reporting period of this report with the project team initiating implementation of the refined driver model dll capable of executing TOSCo vehicle control software libraries in traffic-level simulation and conducted an initial test to confirm the feasibility of the approach.

During the third and fourth reporting periods of this report, the project team initiated implementation of the driver model Dynamic Link Library (DLL) designed for the traffic-level simulation updates and completed the integration of ADTF libraries (vehicle control source code) into the traffic-level simulation driver model DLL.

2.3.6.3 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.

2.3.6.4 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 this third reporting period of this report, the project team conducted an initial review of the TOSCo Functional Safety Concept (FSC) and initiated integration of infrastructure components into the FSC.

During the fourth quarter reporting period of this report, the project team also identified infrastructure items, incorporated infrastructure malfunctions and confirmed that despite identifying a number of infrastructure malfunctions that affect TOSCo operation, the four vehicle hazards remain unchanged.

3 Cooperative Automated Driving Systems

The objectives of this project are to facilitate collaboration and sharing of research results between Crash Avoidance Metrics Partners LLC (CAMP), the United States Department of Transportation (USDOT) and other interested stakeholders to provide input to UDOT'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 supports 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.

3.1 CADS Collaboration Planning (Task 2)

The focus of this task is to establish joint reviews and discussions regarding CADS technologies, enablers and deployment with potential stakeholders to broaden understanding, identify collaboration opportunities and bring industry perspectives to FHWA discussions. As part of this task, CAMP and FHWA jointly established a list of key stakeholders which resulted in a plan to meet directly with each stakeholder to discuss potential opportunities. A potential follow-on project may be developed based on these discussions.

During the first reporting period of this report, a Request for Proposal was issued with responses reviewed and potential suppliers identified, and an infrastructure partner interested in participating in a follow-on Improved Mobility (IFM) research project to prove:

- System Engineering Support
- Hazard Analysis
- Architecture & Algorithm Development
- Simulation & Performance Analysis

During the second reporting period of this report, the team held a one-day face-to-face workshop with FHWA to explore the integration of CAMP's IFM concept with the FHWA's Cooperative Automation Research Mobility Applications (CARMA) initiative.

A one-day face-to-face workshop was held with the FHWA to review the output of the IFM Project focusing on the application of the Functional Safety Process during the third reporting period of this report.

During the fourth reporting quarter of this report, the project team continued dialogue with FHWA considering potential options for future project activities.

3.2 CADS Roadmap Review (Task 3)

The objective of this task is to review and discuss FHWA's roadmap for cooperative automation research. The results of these discussions will include a list of CADS research topics for potential collaboration and will help guide the interactions with potential stakeholders under the CADS Collaboration Planning Task (Task 2) . During the first reporting quarter of this report, the team continued to refine the proposed Research Roadmap for IFM. The project team developed a draft framework for integrating CAMP's IFM concept with FHWA's IHP initiative during the second reporting quarter of this report. During the third and fourth reporting quarters of this report, the project team continued discussions with FHWA regarding integrating CAMP's IFM concept with FHWA's IHP initiative.

3.3 Improved Freeway Mobility (Task 4)

Under this task, the CADS Project Team is reviewing relevant FHWA research on the use of CAVs to improve freeway mobility including use cases, simulations and benefits estimates in order to select concepts of interest, develop a high-level ConOps and the establishment of System Requirements for a proposed CADS. If mutually agreed between CAMP and FHWA, a plan for the next stages of the improved freeway mobility system development will be included as part of the follow-on project proposal.

During the first reporting quarter of this report, the project team reviewed FHWA Connected Automation program documents and provided feedback regarding the following:

- CARMA Testing and Evaluation of Research Mobility Applications
- Examination of the relationships between Transportation System Management and Operations (TSMO) Strategies and Cooperative Automated Driving Systems: High-level Concept of Operations V3.1

During the second reporting quarter of this report, the project team delivered the draft ConOps, High-level Requirements and Functional Safety Concept document for IFM. The efforts under this task concluded October 31, 2019.

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 is 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). High-level project goals are to:

- Demonstrate the flexibility and utility of reconfigurable V2I data exchange by showing:
    - Two-way data exchanges between vehicles and a TMC operations under real-world conditions
    - Infrastructure applications which transform V2I data into actionable information
- Develop, implement, and evaluate exemplar TMC applications that:
    - Help address local roadway operational conditions and needs
    - Show the range of applications which may be supported by flexible V2I messaging structure

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 will 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 will create a bench-test reference system including communication mechanisms and the functionality to demonstrate flow and processing of message to support the anticipated 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 will conclude the project at the end of Phase 1. As a result, the EDCM Technical Management Team (TMT) and the supporting project team revised the Phase 1 timeline as follows:

- The effort to build test vehicles for proof-of-concept and test track testing scheduled in Phase 2 was stopped and focus commenced on messaging framework proof-of-concept testing using a PC-based bench in Phase 1

- Virginia Tech Transportation Institute (VTTI) initiated development on PC-based test bench software to emulate TMT back office server system and vehicle operation in the EDCM architecture
- EDCM Phase 1 will continue technical operation through June 30, 2020 as a no-cost extension to provide the following:
  - Task 1 – Continue Technical Project Management
  - Task 2 – QA/QW System Requirements Document to CV FPS
  - Task 3 – Stopped development of the Project Plan with stakeholder VDOT
  - Task 4 A & B – Develop test bench setup using PC for Query and Response Message communications and message parser for limited use cases
  - Task 5 – EDCM ConOps and Supported Use Cases Document
  - Development of EDCM Phase 1 Project Document

4.1 Stakeholder Outreach and General Coordination (Task 2)

During the first reporting quarter of this report, VTTI engaged with partner and stakeholder Virginia Department of Transportation (VDOT) and conducted workshops with four out of nine districts in Virginia. The districts were selected based on geographical locations that represent rural and urban areas, various roadway configuration and traffic conditions. The purpose of the workshops was to obtain a range of potential use cases from the perspective of the road operators and transform use case information into requirements for EDCM architecture and initial applications. Attendees to the workshop included a mix of operators, TMC managers, engineering and IT. The following four workshops were conducted.

District Name	Date	Duration
Salem	August 15, 2019	3 Hours
Northern Virginia (NoVA)	August 26, 2019	3 Hours
Richmond	August 29, 2019	4 Hours
Hampton	October 1, 2019	3 Hours

The EDCM Project coordinated with CV PFS lead through weekly technical meetings for QA/QW application and system requirements. This coordination continued throughout the reporting period of this report.

During the second reporting period of this report, the EDCM Project technical update was presented at the CV PFS face-to-face meeting on December 11, 2019 in Tampa, Florida.

A presentation was given for 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 during the third reporting period of this report.

4.2 Coordinated Project Planning with Participating Stakeholders (Task 3)

During the second reporting period of this report, the following anticipated schedule of coordination activities for Proof-of-Concept (PoC) with partnering agency VDOT was developed. However, the activities were not completed due to the cancellation of Phase 2.

Milestone	Completion Date	Status
Technical Collaboration	Ongoing throughout project	Ongoing
Use Case Workshops	October 2019	Completed
Design Review 1	October 2019	Completed
Design Review 2	April 2020	
Design Review 3	June 2020	
Design Review 4	August 2020	
Design Review 5	October 2020	
Site Preparation	August 2020	

4.3 EDCM Architecture and Data Query & Response (DQR) Framework (Task 4)

During the first reporting period of this report, the TMT focused on query and response message communication protocol for two-way information and data exchange between the TMC and the connected vehicles using both cellular and Dedicated Short-range Communication (DSRC) communications. The TMT also 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. Other criteria considered for evaluating the messaging language were a smaller footprint for on-board processing unit, easy to implement and provide backward and forward compatibility. The team selected eXtensible Markup Language (XML) for the purpose.

During the second report period of this report, for Tasks 4A, 4B and 4C, (slated to begin in Phase 2), the TMT developed XML for Query Message from the TMC and Query Response from the vehicle. The TMT developed XML schema to describe and validate the structure and the content of XML elements, attributes and data types. The TMT also developed query messages in XML for several use cases identified from the VDOT workshops and tested the correctness of the message against the defined schema. The schema provides the mechanism for querying vehicle status data under varying conditions to support local and regional needs. DENSO, the supplier for the in-vehicle system development, began building the query message parser.

The TMT continued to develop the XML for the Query Message from the TMC and Query Response from the connected vehicle for Tasks 4A, 4B and 4C during the third reporting period of this report. The TMT also concluded development of schema and tested for messaging. The development of Query Message in XML for several use cases were identified from the VDOT workshops and were tested for correctness of the message against the defined schema. In this reporting quarter, VTTI

software development engineers began implementing message parsing for QM and RM for bench testing.

In the fourth reporting period of this report, the TMT completed development of XML schema for QM and QR for Tasks 4A, 4B and 4C. The schema allows for setting geographical and vehicle dynamic data requests from the 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 for QM from TMC and QR from a connected vehicle and validated for correctness of message structure and schema elements. The VTTI software development team implemented the schema and message parsing for QM and RM for the reference bench test system. This task is concluded.

4.3.1 TMC Back-office Interface and Information Process (Subtask 4D)

Activity for this Subtask began in the third reporting period of this report. The activity in this Subtask was originally slated for Phase 2 of the EDCM Project. However, the TMT decided to pull it ahead into Phase 1 to validate developed flexible message scheme and demonstrate the functionality on the bench. The VTTI software development team implemented communication protocol for establishing TMC connectivity with CVs for the reference bench test system and developed a TMC back-office communication interface with CV for QM and information processing of RM.

This activity was completed in the fourth reporting period of this report.

4.3.2 EDCM ConOps and Supported Use Cases (Task 5)

A draft version of the EDCM ConOps and supported use cases document was developed during the second reporting quarter of this report. The EDCM ConOps document was finalized and a document walkthrough was conducted by members of the USDOT/FHWA, Volpe, CV PFS, V2I-2 Consortium Participants and VTTI during the third and fourth reporting quarters of this report. The final version of the document will be submitted through the CAMP Publication Review Process prior to posting on the CAMP Website. This Task is concluded.

4.4 Queue Advisory/Queue Warning (QA/QW) System (Task 6)

During the first, second and third reporting quarters of this report, the TMT worked on defining system requirements for QA/QW application to support low-, medium- and high-fidelity application in the vehicle. The level of information from a low- to high-fidelity application varies from minimal basic information about a queue on the roadway to more detailed information at lane level including locations of front and back of queue, shock wave speed (queue growth rate), and lane-level map of queue. The TMT also 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 element for RSM to support in-vehicle QA/QW application.

During the fourth reporting quarter of this report, the TMT completed the QA/QW application system requirements document in coordination with the CV PFS companion project. The document details the requirements for TMC and CV for data sampling for detecting and formation of a queue in a work zone for low- and high-fidelity use cases including required data elements in RSM to support in-vehicle application. The completed document will go through the CAMP Publication Review Process before posting on the CAMP website.

4.4.1 Support CV PFS – Development of QA/QW ConOps (Subtask 6A1)

The EDCM TMT continued with discussions regarding the QA/QW application and system-level requirements with the Connected Vehicle Pooled Fund Study (CV PFS) leads in support of the ConOps during the first, second and third reporting quarters of this report.

During the second reporting quarter of this report, the TMT, in an effort to support CV PFS for analyzing traffic congestion and formation of queue(s), collected vehicle path data along I-696 West- and East-bound travel in Michigan during the evening rush hour. CV PFS used this data in their simulation model to identify back of queue (BOQ) and Start of Queue (SOQ) for main and sub-queues. The results were presented at the CV PFS meeting on December 10, 2019 in Tampa, Florida.

During the fourth reporting quarter of this report, the TMT reviewed and provided comments to the draft version of QA/QW ConOps document from CV PFS.

4.5 EDCM Phase 1 Completion

To conclude Phase 1 of the EDCM Project, and to verify the concept and design of the EDCM, the software development 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 the feedback received during the stakeholder engagement, six use cases were selected and implemented to represent the conditions of interest to the stakeholder. The implemented use cases are queue detection, hard braking, late merge (in the context of work zone monitoring), weather events, general traffic monitoring and road segment evaluation. In addition, an On-board Unit (OBU) emulator was developed to monitor vehicle CAN data in response to the query from the TMC. The end-to-end system information from the roadway is displayed on the TMC console in real time including vehicle movement for TMC operator.

To verify the design and operation, two vehicles were instrumented and used to drive a test course with scripted events corresponding to the different use cases. Live video from the vehicles was sent to the simulated TMC console to allow for simultaneous recording of the live video and the display of the client application. This data, along with log files from the vehicles and TMC servers, was analyzed to demonstrate the complete operation of the system from QM creation to RM data display in a TMC-type environment.

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.

5.1 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.

5.1.1 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. Specific accomplishments include:

- The work zone mapping software toolchain developed under the CAMP V2I Safety Applications (V2I-SA) Project is now available for download from CAMP's website (https://campllc.org) under the software/tools tab.
- The mapping toolchain was also provided to Saxton Transportation Operations Laboratory (STOL) for integrating into mapping toolset with the intersection mapping tool developed by Leidos at STOL. The work zone map is now integrated into the toolset.
- On July 17, 2019, at the Automated Vehicle Symposium, the mapping software toolchain was presented at the Advanced Smart Work Zone Solutions panel on Work Zone Data Exchange.
- 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 group developed a proposal for a NOCoE hosted webinar to share lessons learned and promote broader use of the work zone mapping software tool chain. The webinar occurred on November 22, 2019 and included the relationship to WZDI, and lessons learned from initial utilization in Texas and Arizona.
- The group planned to capture, and document lessons learned from initial deployments.
- Developed 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 FHWA V2X Mapping Project as a potential source of enhanced mapping tools and support for IOOs.

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

The EDCM Project Principal Investigator (PI) and the 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, further testing and verifications of seven intersections in Ann Arbor, Michigan continued using the test and verification tool. Additional inconsistencies were discovered in a SPaT message on actuated intersections. It was discovered that in the SPaT message, the time remaining for the current phase is zero, but the current phase is still active. There is no further indication in the subsequent SPaT message about when the current phase is going to change to the next phase. This can be potential safety hazard for the Red Light Violation Warning (RLVW) application. The observed inconsistency and recommended solution for the SPaT message will be incorporated into the Clarification for Consistent Implementation (CCI) document.

With the ongoing effort on SPaT/MAP verification, a document describing “Test Procedure for Verifying SPaT and MAP Messages” was developed. The draft version of the document was provided to SPaT/RLVW working group members for review and comment.

FHWA shared “Triple Spreadsheet,” the SPaT and MAP Data Object Alignment spreadsheets developed for conformance check by the CV pilots. The spreadsheet provides a list of all data objects defined as either mandatory or optional in the SAEJ2735 data dictionary and is marked against what was implemented as mandatory or optional at the pilot site. The provided data is for NYC and Tampa CV Pilot sites. Since application requirements are not provided with the list, rationale for making data elements as mandatory or optional by the pilots is not described. Also, no details of any inconsistencies, gap or ambiguities discovered in the standard is described. The “Triple Spreadsheet” does not provide any additional information for incorporating into the CCI document.

The inconsistency discovered in the received SPaT at an actuated signalized intersection in Ann Arbor, Michigan was presented at the working group as well as the SAE V2X communications Traffic Signal Application (TSA) Technical Committee (TC) during the second reporting period of this report. The current phase and associated time are not corelated in the message. The inconsistency and recommended solution in the SPaT message will be incorporated in to the CCI document. With the ongoing effort on SPaT/MAP verification, the document entitled “Test Procedure for Verifying SPaT and MAP Message” was presented at the Connected Fleet Challenge webinar on November 21, 2019. The working group developed a draft version of the document entitled “Enabling 2022” for Connected Intersection Communications with Production Vehicles by 2022. In the document, seven needs are identified to enable nationally interoperable connectivity between the production vehicles and the connected signalized intersections.

In the third reporting period of this report, the working group continued to refine the concept paper on Enabling Connected Intersections, developed seven major activities, leveraged other parallel activities

and established how to coordinate for activities. In addition to this activity, CAMP Participants held discussions to provide assistance in the Mcity Project Proposal for connected signalized intersections for CCI conformance. Also, CAMP developed a self-funded proposal to assist and complement the Mcity Project for connected signalized intersection verification focusing on the development of functional safety, test procedures and a test tool. CAMP Participants continued discussions with CV PFS for the MAP Verification Tool Project and other relevant projects for potential collaboration. A face-to-face meeting was held on February 27, 2020 in Washington DC with the IOO/OEM Forum.

During the fourth period of this report, the working group continued to refine the concept paper on Enabling Connected Intersection, 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 is developing a five-phase testing and verification approach for enabling connected intersection for deployment readiness to complete ongoing verification. CAMP Participants also held discussions and assisted in the CV PFS Project for connected signalized intersection for CCI conformance. A CAMP proposal was developed to assist and complement the Mcity/CV PFS Projects focusing on development of functional safety, test procedures and test tool.

5.1.3 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.

5.2 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 support is the ongoing development of the SAE J2945/4 RSM which is needed to support the deployment of infrastructure message enabling in-vehicle RSZW and QA/QW developed under the V2I-SA Project.

In the first and second reporting quarters of this report, monthly meetings for the TSA TC continued. The TSA TC, responsible for development of J2945/A (formerly J24945/10), agreed to rename the document from “Recommended Best Practices for MAP-SPaT Development” to “MAP-SPaT Message Deployment – Intersection Operations” and will include minimum performance requirements and implementation guidance as addressed in the CCI as well as lessons learned from pilots and other deployments. Since the newly awarded USDOT project on Connected Signalized Intersection was awarded to develop a document to address inoperability issues for standardization based on the CCI document, the TC members decided to wait before moving forward with the J2945/A until next year in order to obtain more detail about the USDOT effort and see how the USDOT effort can be supported by the TC members.

The committee is also responsible for the development of J2945/11 – Recommended Practices for Signal Preemption Message Development. Recommendation in the documentation will include examples and reference implementation from Utah DOT and Tampa CV Pilot.

In the IA TC, the mapping task force is formulated to review current mapping as defined in J2735 which is intersection-centric and does not address the needs of RSZW, Curve Speed Warning (CSW) and future V2I applications. Additionally, the current mapping definition does not provide extensibility

and support for a large complex map message. Work in the mapping taskforce continued to review current activities in ISO and liaison with On Road Automated Driving (ORAD) committee members for mapping needs.

A merger of the TSA and IA committees was approved to reduce the administrative logistical overhead of managing two separate committees and meetings. Almost all members are common between the two groups and have closely coupled charters and activities.

In the third report quarter of this report, IA TC reviewed the final version of J2945/3 (Road Weather) for ballot and approved it. In addition, the committee is working on J2945/4 (Road Safety Message) and J2945/A (SPaT and MAP recommended practice) which are on hold pending what information comes from the USDOT/ITE Connected Intersection Project, J2945/B (Signal Priority and Pre-emption) and J2945/C (Traffic Probe use and Operation). The mapping task force in the IA TAC continued discussions on developing next generation mapping to support the growing need for V2X applications since the current mapping mechanism provided in J2735 is intersection centric and not suitable and scalable to address the needs of current and future V2I applications. In addition, application testing for the Interoperability Task Force was formed.

In the fourth reporting quarter of this report, since the merger of the Infrastructure Application (IA) and TSA TC into the IA TC, a Work in Process (WIP) for development of standard for “Lane-level and Road Furniture Mapping for Infrastructure-based V2X Applications” for next generation mapping was created as J2945/A. Also, for J2945/B, “Recommended Practices for Signalized Intersection Applications” was expanded to include applications related to signal priority and preemption. The IA TC held a walkthrough of needs and requirements for J2945/C, Traffic Probe use and Operation. Also, in the IA TC, the mapping task force continued discussion on developing next generation mapping to support the growing needs for V2X applications since the current mapping mechanism provided in J2735 is intersection centric and not suitable and scalable to address the needs to current and future V2X applications. For the ITE-led, USDOT-funded, RSU Standardization and Connected Intersection (CI) Projects, ConOps user needs for the RSU Standardization Project were conducted and the team is now working on requirements, and in the CI Project, scope has been defined and six task forces have been formulated.

5.3 Support for Other Stakeholders

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.

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
DQM	Data Query Message
DQR	Data Query Response

Acronym	Definition
DSRC	Dedicated Short-Range Communications
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
GUI	Graphical User Interface
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
MII	Mobile Intelligent Infrastructure
NOCoE	National Operations Center of Excellence
NoVA	Northern Virginia
OBE	On-board Equipment
OBU	On-board Unit
OEMs	Original Equipment Manufacturers

Acronym	Definition
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
QM	Query Message
QR	Query Response
RM	Response Message
RLVW	Red Light Violation Warning
RSM	Roadside Safety Message
RSU	Roadside Unit
RSZW	Reduced Speed/Work Zone Warning
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
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)

Acronym	Definition
TSA	Traffic Applications Signal
TSMO	Transportation System Management and Operations
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UCR	University of California Riverside
UMTRI	University of Michigan Transportation Research Institute
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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