Development of Vehicle-to-Infrastructure Applications Program

Fifth Annual Report

July 1, 2018 through June 30, 2019

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16. Abstract

This report documents the work completed by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium during the fifth year of the "Development of Vehicle-to-Infrastructure Applications (V2I) Program." Participating companies in the V2I Consortium during this period were Ford, General Motors, Hyundai Motor Group, Honda, Mazda, Nissan, Subaru, Volvo Truck, and VW/Audi. The period covered by the report is from July 1, 2018 through June 30, 2019. 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 Vehicle-to-Infrastructure Safety Applications (V2I-SA), Traffic Optimization for Signalized Corridors (TOSCo), Cooperative Automated Driving Systems (CADS), Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory / Warning (QA/QW) System and Stakeholder Engagement and Outreach. This report provides a summary of key project activities and accomplishments for the period.

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Executive Summary

This document presents work carried out under the Development of Vehicle-to-Infrastructure (V2I) Applications Program (V2I Program), through Cooperative Agreement No. DTFH6114H00002, during the fifth year of program operation. The period covered by the report is from July 1, 2018 through June 30, 2019. 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 fifth 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 and Shulman and Geisler, 2018, Report No. FHWA-JPO-18-704.)

V2I Program Administration

Project Status: In Progress

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 are Ford, GM, Honda, Hyundai Motor Group, Mazda, Nissan, Subaru and VW/Audi. 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.
- 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

Administered the following active projects during this annual reporting period:

- V2I Safety Applications (V2I-SA) Project – completed May 2019
- Cooperative Automated Driving System (CADS) Project – **ongoing**
- 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 I: Modeling and Analysis – completed June 2019

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 Consortium considers 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.

Vehicle-to-Infrastructure Safety Applications Project

Project Status: Completed

Project Team: V2I-Consortium

Project Timeline: September 2014 – May 2019

The objective of the V2I-SA Project was to develop and test a cross-section of V2I safety applications that focus on infrastructure interaction and deployment. The safety applications initially considered in the project included: Red Light Violation Warning (RLVW), Emergency Vehicle Priority Warning (EVPW), Curve Speed Warning (CSW), Spot Weather Impact Warning (SWIW), Reduced Speed / Work Zone Warning with Lane Closure (RSZW/LC), and Stop Sign Gap Assist (SSGA).

Significant Activities and Key Findings

- Completed technical assessment of the candidate safety applications, identification of application selection criteria and a selection process for development, field testing and

demonstration. Three applications were subsequently selected for development in the project: RLVW, CSW and RSZW/LC.

- Preparation of development plans for the selected applications
- Developed a prototype, over-the-air, Dedicated Short-Range Communications (DSRC) Basic Information Message (BIM) for the CSW and RSZW/LC applications along with a rationale for why this message is needed. This work provided significant contributions to the ongoing development of the Roadside Safety Message (RSM) standard in SAE J2945/4. When completed, the RSM is expected to incorporate the data elements contained in the BIM prototype message developed for this project and the data elements from the infrastructure message called the Basic Infrastructure Message.
- Development of the selected V2I safety applications for test and evaluation
- Integration of the applications into seven test vehicles and preparation of transportable intersection equipment to support testing in the project
- Development of initial test procedures and documentation of the initial test results
- Development of Objective Test Procedures (OTPs), completion of objective testing, and documentation of application performance and analysis results
- Development of a process to automatically generate intersection maps (in SAE J2735 MAP Message format, MAP) using Basic Safety Messages (BSMs) obtained by Roadside Units (RSUs). The process was evaluated using BSM data collected at five intersections used in the USDOT Safety Pilot Model Deployment Program.
- Demonstration of the RLVW, CSW and RSZW/LC applications for V2I stakeholders, including the Connected Vehicle (CV) Pilot sites, Smart City Challenge finalists, the V2I Deployment Coalition, USDOT, and automotive industry representatives. The demonstration was held April 19-22, 2016 at a test track in Michigan.
- Conducted workshops to study the feasibility of adapting the RLVW application to actuated traffic signals. The workshops were designed to gain knowledge of the actuated signal controller technology and to assess the performance impact on current RLVW application and possible resolution.
- Demonstration of the RLVW, CSW, and RSZW/LC applications in Washington, DC on January 24-25, 2017. The demonstration, held in conjunction with the Washington Area New Automobile Dealers Association's (WANADA) connected vehicle technology events, involved participants from the media, automotive industry and governmental units.
- Completed performance evaluation of CSW and RSZW/LC applications on public roads. Test sites, located in Southeast Michigan, included freeway exit and entrance ramp curves and a work zone on I-75 near State Highway M-59 in Auburn Hills.
- Completed the Final Report on work completed in Tasks 2 through 12 of the project and was submitted to FHWA on July 27, 2017
- Completed Version 1.2 of the Signal Phase and Timing (SPaT) Challenge Verification Document and delivered the document to the IOO/OEM Forum on November 7, 2017. The Task 15 interim report on the intersection verification process was also prepared and delivered to FHWA on December 15, 2017.
- Completed the Task 14 Interim Report for Development of Software Toolchain to Map, Visualize and Build Message for Connected Work Zone Safety Application. The report was delivered to FHWA on October 30, 2018.

- Completed the Task 13 Interim Report for Connected Work Zone Deployment Guidelines in cooperation with TTI (TxDOT). The report includes lessons learned from real-world deployment and associated technical challenges from the RSU vendor and working with a multi-agency organization. The report was delivered to FHWA on June 6, 2019.

Traffic Optimization for Signalized Corridors Project

Project Status: In Progress

Project Timeline: April 2015 – December 2021

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. (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

- 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

Cooperative Automated Driving Systems (CADS)

Project Status: In Progress

Project Team: CAMP LLC

Project Timeline: July 2018 – October 2019

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

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

Project Status: Awarded May 2019

Project Timeline: May 2019 – November 2021

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).

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.

Significant Activities and Key Findings to Date

Project Kickoff Meeting – June 2019

Stakeholder Engagement and Outreach

Project Status: Awarded March 2019

Project Timeline: March 2019 – January 2022

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 outreach with the IOOs, the following activities occurred:
  - Reviewed and updated the SPaT/MAP Verification Tool and Clarifications for Consistent Implementations (CCI) document
  - Provided connected WZ Mapping S/W Toolchain support to STOL and the University of Arizona (Maricopa County)

1 V2I Program Administration

This document presents the Fifth 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, 2018 through June 30, 2019. 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 Consortium was formed in 2014 to conduct the projects awarded under the Cooperative Agreement. Current V2I Consortium Participants are Ford, GM, Honda, Hyundai Motor Group, Mazda, Nissan, Subaru, VW/Audi, and Volvo Truck. This Consortium represents a broad range of automotive perspectives from light-vehicle to heavy-truck manufacturers as well as global viewpoints that encompass the U.S., Europe, and Asia. The Consortium Management Committee (CMC) meets 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:

- V2I Safety Applications (V2I-SA) Project – Project was completed May 2019
- Traffic Optimization for Signalized Corridors (TOSCo) Project Phase I: Modeling and Analysis – completed June 2019
- Cooperative Automated Driving Systems (CADS) Project
- Stakeholder Engagement and Outreach Project – Project awarded March 2019
- Event-Driven Configurable Messaging (EDCM) Design & Development and Work Zone Queue Advisory/Warning (WA/QW) System Project – Project awarded May 2019

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.

In addition to overall program administration activities, the structure of the V2I Program Administration Work Order includes efforts to support initiatives related to the Infrastructure Owners and Operators / Original Equipment Manufacturers (IOO/OEM) Forum and SAE standards development. As such, three tasks exist in the work order, as follows:

- 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.
- IOO/OEM Forum (Task 2): This task will focus on the activities associated with participation in the IOO/OEM Forum. The goal of the IOO/OEM Forum is to provide for the exchange of information between OEMs and infrastructure owners and operators that will support the future deployment of V2I and Infrastructure-to-Vehicle (I2V) applications.
- SAE Standards (Task 3): This task will support the development of SAE standards for V2I applications.

Note: Tasks 2 and 3 of the V2I Program Administration Work Order were transferred to the new Stakeholder Engagement and Outreach Project which was awarded on March 1, 2019. As a result, the content for the accomplishment of these tasks for the period of performance from March 1, 2019 to June 30, 2019 will be included in the Stakeholder Engagement and Outreach Project section.

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, 2018, October 30, 2018, January 30, 2019 and April 30, 2019.
- Quarterly Progress Briefings, providing a presentation to FHWA of the work performed in the preceding quarter. Quarterly Progress Briefings were completed on July 18, 2018, October 16, 2018, January 30, 2019 and May 3, 2019.
- 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 Fourth Annual Report for the V2I Program (Shulman and Geisler, 2018, Report No. FHWA-JPO-18-704)

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 and Shulman and Geisler, 2018, Report No. FHWA-JPO-18-704.).

1.2 Outreach to Infrastructure Owners and Operators

The V2I Consortium continued interactions with the IOO/OEM Forum for the period of performance of July 1, 2018 through February 28, 2019 under Program Administration. (Note: the period of performance of March 1, 2019 through June 30, 2019 for outreach to IOO/OEMs will be reported under the new Stakeholder Engagement and Outreach Project.) . In addition to supporting the overall forum activities, the Consortium participated directly in three of the forum's working groups. The activities surrounding these groups are presented below.

1.2.1 Reduced Speed / Work Zone Warning Working Group

The Reduced Speed / Work Zone Warning (RSWZ) Working Group monitored the ongoing smart work zone initiatives and shared information across activities, including those in Michigan, Texas, Arizona, Virginia and the FHWA Work Zone Data Initiative. The group continued to track the progress of the work zone mapping software toolchain developed under the CAMP Vehicle-to-Infrastructure (V2I-SA) Project and planned to promote its use across multiple work zone initiatives to foster the sharing of the lessons learned / suggested refinements to the tool. The toolchain was deployed as part of the I-35 Smart Work Zone initiative in Texas.

Work was also completed on a preliminary Model Concept of Operations describing an Infrastructure System to support the Reduced Speed Zone Warning – Lane Closure Application Signal Phase and Timing (SPaT) / Red Light Violation Warning (RLVW) Verification Working Group.

The V2I-SA Project PI and the V2I Consortium participated in monthly webinars for the SPaT / RLVW Working Group. As a result, the SPaT Challenge Model ConOps document continued to be developed. A draft version 1.6 and a draft of the SPaT Challenge Infrastructure Model Requirements Document Version 1.1 became available for review and comment.

For collaboration, the IOO/OEM Forum met on October 17, 2018 in Washington, D.C. The Utah Department of Transportation (Utah DOT) proposed four (4) phase approaches to verifying transmitted SPaT/MAP data for RLVW. Discussions continued for development of a "Profiles" document framework similar to the European system profile (C-Roads) that defines a minimum set of standards to realize interoperable deployment of roadside infrastructure for the RLVW applications at signalized intersections.

During the fourth quarter of 2018, verification of SPaT/MAP message transmission and testing of RLVW application continued along the Groesbeck Highway corridor in Michigan using the SPaT/MAP visualization tool and test vehicles. Several test runs indicated that not all RSUs along the corridor were always operational. The verification tool was also loaned to researchers at Berkley PATH for verifying intersections along the El Camino Real in Palo Alto, California. These intersections transmit SPaT/MAP and Radio Technical Commission for Maritime Services (RTCM) for GNSS differential correction. These intersections are also enabled for Multi Modal Intelligent Traffic Safety System (MMITSS). Preliminary results indicate that the tool was very easy to setup and use and operates as intended for intersection verification.

1.2.2 Signal Phase and Timing / Red Light Violation Warning Verification Working Group

The Signal Phase and Timing / Red Light Violation Warning (SPaT/RLVW) Verification Working Group was led by the V2I-SA Project Principal Investigator (PI) who coordinated the exchange of information regarding CAMP's V2I projects.

The V2I-SA PI and the V2I Consortium participated in monthly webinars for the SPaT/RLVW Working Group. A ConOps document was developed and a draft version was provided for review and comment. As the SPaT Challenge progressed and state agencies deployed Roadside Units (RSUs), the correctness of received SPaT/MAP messages was addressed. A tool to visually verify and generate a report for received SPaT/MAP messages for an intersection was developed by a supplier based on required functionality as provided by CAMP. The tool displays intersection map received in the MAP message on a Google map and associated signal phase and timing data received in the SPaT message in real-time. Data received in the messages are then logged for post processing and generating a verification report. During the first quarter of this report, CAMP verified more than a dozen intersections using the tool and informed Michigan Department of Transportation (MDOT) about the status for further action as needed. MDOT also used the tool to verify five intersections along the Jefferson Avenue corridor in downtown Detroit, Michigan. The functionality and capability of the verification tool were presented at the SPaT Challenge Working Group webinar on September 10, 2018.

1.2.3 Connected Automation Working Group

The TOSCo Project PI met with the IOO/OEM Forum Connected Automation Working Group monthly throughout the period of performance of this report to provide an exchange of information between the TOSCo Project and the working group members to review preliminary and final simulation results, infrastructure requirements and obtain feedback.

The CADS/IFM Project PI presented periodic updates to the Connected Automation Working Group, providing updates on the project progress and opportunities for IOO representatives to provide feedback on IFM Concept of Operations draft.

1.2.4 Support for SAE Standards Development

Throughout the fifth year of project operations, the V2I-SA Project continued interactions with the SAE Dedicated Short-Range Communications (DSRC) Technical Committee (TC) and the SAE V2I/I2V Task Force. Work in this area consisted of participation in scheduled TC and Task Force meetings to provide comments and answers to questions, as needed, to support the development of standards.

The development of the SAE J2945/4 RSM for Traveler Information and the CAMP-developed RSZW and Curve Speed Warning (CSW) continued during the first and second quarters of this report with major requirements for safety applications including an updated ASN.1 definition and a presentation at the August 2018 SAE DSRC Task Force Committee meeting.

During the third quarter of this report, SAE V2X Communications Steering Committee was organized, and nine technical committees were formulated. Jay Parikh, V2I-SA Project PI, was elected to chair the Traffic Signal Applications (TSA) Technical Committee. The focus of the committee was to develop the J2945/10 document for recommended practices for SPaT/MAP based applications and J2945/11 for signal priority and preemptions. The TSA committee closely collaborated with the Infrastructure

Applications (IA) Technical Committee for common mapping requirements for broader V2I applications that included J2945/3 for Weather, J2945/4 for Roadside Safety Message (RSM) and J2945/12 for traffic probe applications.

2 Vehicle-to-Infrastructure Safety Applications Project

The Vehicle-to-Infrastructure Safety Applications (V2I-SA) Project started in September 2014 and was successfully completed in May 2019. The objective of the V2I-SA Project was to develop and test a cross-section of V2I safety applications that focus on infrastructure interaction and deployment. The safety applications initially considered for further development in the project were: Red Light Violation Warning (RLVW), Emergency Vehicle Priority Warning (EVPW), Curve Speed Warning (CSW), Spot Weather Impact Warning (SWIW), Reduced Speed/Work Zone Warning with Lane Closure (RSZW/LC) and Stop Sign Gap Assist (SSGA). Activities completed in the project included a technical assessment of these applications and the selection of three for development and evaluation within the remainder of the project. The selected applications were RLVW, CSW and RSZW/LC.

2.1 Coordination with Stakeholders

The objectives of this task were to identify stakeholders for the safety applications and subsequently conduct meetings with the identified organizations as needed to support the project tasks. The coordination task continued throughout the project. During the fifth year of program operations, outreach efforts in the V2I-SA Project included interactions with the Infrastructure Owners and Operators / Original Equipment Manufacturers (IOO/OEM) Forum, the Connected Vehicle Pooled Fund Study (CVPFS) and the Michigan Department of Transportation (MDOT).

Throughout the period of performance of this report, the V2I-SA Project continued to hold monthly update meetings with MDOT to coordinate activities underway in Work Zone Mapping Task and in the SPaT Challenge Intersection Verification Task.

In addition, the portable tool to visualize received SPaT/MAP messages continued to be evaluated at several MDOT intersections in the Detroit area. This work was conducted as part of a development effort underway with an infrastructure equipment supplier. Information acquired during the evaluations was provided to the supplier for further refinement of the tool. CAMP provided MDOT the tool and support to verify several intersections on the Jefferson Avenue corridor in Detroit, Michigan. The tool evaluated presents the SPaT and MAP information from messages sent by an RSU on the display of a tablet computer, permitting easy comparison with the actual signal status and lane configurations at the intersection. The need for such a tool was identified during work previously completed in the SPaT Challenge Verification Task and in discussions at the IOO/OEM Forum.

The V2I-SA Project Principal Investigator and the V2I Consortium Participants continued to participate in monthly webinars for the SPaT/RLVW Working Group.

On October 17, 2018, the project participated in the IOO/OEM Forum meeting at American Association of State Highway and transportation Officials (AASHTO) headquarters in Washington D.C. to present results from the verification of several intersections in Southeast Michigan using the SPaT/MAP verification and report generating tool and work zone mapping and message building toolchain.

The V2I-SA Project PI participated in the Connected Vehicle Pooled Fund Study (CVPFS) meeting in Atlanta, Georgia on December 4 – 5, 2018. At this meeting, the Event Driven Configurable Messaging (EDCM) Project concept was presented and discussed with the attending stakeholders.

Also in December 2018, the SPaT/MAP visualization tool was given to researchers at Berkeley PATH to evaluate Multi Modal Intelligent Traffic Safety System (MMITSS)-enabled intersections in the California Connected Vehicle (CV) testbed along the El Camino Real in Palo Alto, California as these intersections transmit SPaT/MAP and RTCM correction messages.

2.2 Adaptation of Reduced Speed Zone/Lane Closure Warning in Texas I-35 Corridor Construction Project

In this task, the RSZW/LC application, developed earlier in the V2I-SA Project, was evaluated through pilot field testing on selected sections of the I-35 corridor under construction in Texas. Work in this task was initiated in July 2017.

A regular cadence of meetings was identified with the Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI) to support the exchange of information needed to complete this task, address questions and issues that might arise during task execution and review task progress. The discussions that continued into the third quarter of 2018 centered on procuring equipment for test vehicles and infrastructure equipment, RSUs for application testing, placement of RSUs in the construction zone and the interface with the Lonestar backend server for lane closures. The V2I-SA team provided schematics and other relevant information for building the reference vehicle for work zone mapping using the toolchain and testing the RSZW/LC application in the mapped work zone. Nine Roadside Units (RSUs) were acquired and deployed in the field covering nine (9) miles along I-35 in Temple, Texas. The RSUs received messages from the TxDOT Lonestar back-end servers for transmitting to vehicles equipped with an On-board Unit (OBU) for the RSZW/LC safety application. In addition, the BSM was collected by the RSUs for queue warning and other mobility related analysis.

As regular meetings continued with TxDOT and TTI, the V2I-SA Project Team provided the following support/assistance to TTI during the fourth quarter of 2018:

- Provided hardware and software configuration support for instrumenting a reference test vehicle and infrastructure equipment for collecting vehicle path data for work zone mapping and testing the RSZW/LC application on the generated work zone map using the toolchain
- Provided the software toolchain and support in setting up the software on a laptop
- Provided GPS receiver configuration setup to collect vehicle path data to build work zone map.
- Assisted in operating the toolchain to map approximately 20 km long, three (3)-lane I-35 Freeway near Temple, Texas for both the north and south directions. The generated map is segmented into five segments to meet message payload requirements for transmission.
- Provided the CAMP-developed RSZW/LC application and assisted in configuring the OBU in the reference vehicle for testing the application
- Continued assisting the TTI team for placement, set up and configuration of the RSU for transmitting the work zone map message

The V2I-SA Project team continued the regular schedule of meetings on a weekly basis with TxDOT and TTI into the first quarter of 2019 and continued to support TTI in the following areas:

- Assisted TTI in operating the toolchain to map approximately a 20 km long, three (3)-lane section of the I-35 Freeway near Temple, Texas for both north and south directions. The generated map was segmented into several segments in order to meet message payload requirements for transmission.
- Provided the CAMP-developed RSZW/LC application and assisted in configuring the OBU in the reference vehicle for testing the application.
- CAMP assisted TTI in the analysis of work zone test data collected using the RSZW/LC application and identified an anomaly related to one of the test runs exhibiting a constant GPS positioning offset. TTI further conducted tests in order to identify the GPS issue. Since this version of the RSZW/LC did not support a single lane with multiple-lane closures, TTI could not test this capability for the mapped work zone using the application. The focus of this task has been to apply the mapping software tool chain in real-world work zones for the development of a guidelines document from lessons learned. The CAMP developed RSZW/LC application was revised to support newly developed RSM and was used to validate the work zone map and the developed RSM for a work zone. Test results indicated that the correct work zone maps were being generated using the tool chain.

During the second quarter of 2019, the V2I-SA Task 13 Final Report for Connected Work Zone Deployment Guidelines was cooperatively developed by the V2I-SA Technical Management Team (TMT) and TTI (TxDOT). The report included lessons learned from real-world deployment and associated technical challenges from the RSU vendor and working with multi-agency organizations. The completed final report was submitted to FHWA on June 6, 2019.

2.3 Work Zone Mapping

The goal of this task was to develop a dynamic mapping technique to assist IOOs in preparing near real-time work zone maps to support the RSZW/LC application. Work in this task started in April 2017. The mapping technique developed consists of a software toolchain with four applications. These are described below:

- Vehicle Path Data Acquisition System – collects vehicle path data using an instrumented test vehicle
- Work Zone Map Builder – processes previously collected vehicle path data and generates a work zone map required for the RSZW/LC BIM
- Work Zone Map Visualizer – generates the work zone map in human-readable form (i.e., in eXtensible Markup Language, or XML, format) and overlays it on a Google satellite-view map for visual verification
- CV Message Builder and Verifier - creates an encoded map message, based on Unaligned Packed Encoding Rules (UPER), from the XML map format and decodes the map message back to XML for verification. This encoded message is in an RSU-independent format.

In the third quarter of 2018, the testing of end-to-end work zone mapping and message building toolchain along with an updated RSZW/LC application based on RSM concluded. Testing was completed on a 3.5 km long four (4)-lane arterial road work zone along the Woodward Avenue corridor

in Southeast Michigan. As a result, several refinements and improvements were made to the software tools to support message segmentation for a long and complex work zone for which the message payload exceeds the message size requirement or exceeds the number of node points that represent the work zone map as specified in SAE J2735. This flexibility allows for the transmission of multiple message segments that represent the entire work zone and does not require the deploying agency to build multiple work zone maps. The RSZW/LC application was updated and successfully tested on a work zone consisting of multiple message segments.

The testing of the end-to-end work zone mapping and message building toolchain along with an updated RSZW/LC application based on RSM was completed during the fourth quarter of 2018. The mapping and message building toolchain and the RSZW/LC application performed as intended including message segmentation.

This task was concluded with the submission of the final report to FHWA on October 30, 2018. The final report included user guides for the work zone mapping and message building toolchain.

3 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, TTI, the University of Michigan Transportation Research Institute (UMTRI), and the University of California Riverside (UCR). TOSCo uses wireless data communications from 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. The significant accomplishments and key findings to date reflect TOSCo Phase 1 activity.

3.1 Simulation Modeling and Performance Analysis

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.

3.1.1 Estimate Potential Benefits

Work on the benefits estimation subtask began on November 1, 2017 and was concluded in September 2018. Results were presented during the Review Meeting #6 with FHWA on October 22, 2018.

During the first quarter of 2019, the TOSCo Team reassessed simulation assumptions as a result of unexpected results for the high-speed corridor. Investigation of actual acceleration levels for State Highway 105 found that acceleration levels were considerably lower (~2.5 vs 3.5 m/sec^2) than VISSIM default acceleration for surrounding traffic. Results were recalculated (AM and PM peak directions) using new measured acceleration values for surrounding traffic. The acceleration for TOSCo vehicles remains unchanged at 1.5 m/sec^2. The Simulation Interim Report was updated with the latest results and was submitted to FHWA on January 25, 2019.

[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.

3.2 System Architecture and Algorithm Development

The objective of this task was to establish the TOSCo system architecture and develop the vehicle and infrastructure algorithms needed to support TOSCo functionality. The architecture and algorithms were incorporated into the simulation environment discussed above.

3.2.1 Algorithm Development

The objective of this subtask was to develop the algorithms needed to implement the TOSCo function(s). Phase I algorithm development occurred in the simulation environment and was assessed based on performance metrics that the TOSCo Project Team defined. The Project Team evaluated multiple TOSCo implementation options that were available within the system architecture developed in previous subtasks.

During the third quarter of 2018, the TOSCo Project Team focused on refining the Coordinated Stop / Coordinated Launch operating modes and developed a plan to achieve completion of the vehicle algorithm refinement by year-end. The Creep operating mode was refined by the TOSCo Project Team in the fourth quarter of 2018.

In the first quarter of 2019, the team created baseline simulations for the Vehicle Simulation Interim Report and identified necessary improvements in the Speed Profile Computation. The team also implemented new speed profiles for Coordinated Stop, Coordinated Launch and Creep operating modes in the vehicle-level simulation environment.

The TOSCo Project Team implemented the Speed profiles for Coordinated Speed Control, made improvements to the calculation of the speed profile solution space, enhanced and parameterized the TOSCo longitudinal controller, revised the Coordinated Launch operating mode to cover edge cases and completed and delivered the Vehicle-level Simulation Report on June 28, 2019 in the second quarter of 2019. The findings of this report were incorporated into the TOSCo Phase I Final Report.

3.3 System Specifications and Hazard Analysis

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 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.

3.3.1 Refine Architecture and Algorithm Specifications

The objective of this subtask was to refine the TOSCo system architecture and algorithm specifications based on the performance observed in simulation. However, initial simulations results were needed prior to refining the architecture and algorithm specification. To coordinate with the revised completion dates, the period of performance of this task was extended from February 28, 2018 to November 30, 2018.

The Project team reconvened meetings with kVA to assess whether changes to the TOSCo vehicle algorithm affected previously accomplished hazard analysis. One new factor under consideration was the effect of inaccurate information from SPaT / RSM and how it affected hazard analysis since it is possible for RSEs to broadcast incorrect information.

During the fourth quarter of 2018, the TOSCo Project Team incorporated refinements in the system architecture and algorithms into the system specification and reviewed these changes for their implications to the preliminary hazard analysis. Interim milestones documenting these refinements were completed with the submission of the TOSCo Functional Safety Concept and Hazard Analysis Interim Report. The report was submitted to FHWA on May 6, 2019.

3.4 TOSCo Phase 2 Planning

The objective of this task was to build upon the results obtained in Phase 1 to develop technical and cost proposals for follow-on work that will focus on evaluation of TOSCo functionality along the actual urban arterials that were selected for simulation modeling. The Project Team initiated an update to the framework originally provided in the Phase 1 Statement of Work. Draft technical and cost proposals for the TOSCo Phase 2 Project were prepared and delivered to the FHWA on March 29, 2018 and resubmitted on July 31, 2018. The revised proposals involved splitting the Phase 2 Period into two one-year terms with added milestones and deliverables to define the two terms.

3.5 Coordination and Outreach

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. Activities during the period of this report included:

- The TOSCo PI met with the IOO/OEM Forum Connected Automation Working Group in July , August, September, October and December 2018 to present the TOSCo Project status and preliminary simulation results.
- The TOSCo PI met with the IOO/OEM Forum Connected Automation Working Group in January, February and March 2019 to present the TOSCo Project status and updated infrastructure requirements.
- The TOSCo PI met with IOO/OEM Forum Connected Automation Working Group in May and June 2019 to present the TOSCo Project status, present updated infrastructure requirements and provide the establishment of a significant connected automation presence at the 2020 SAE World Congress.
- The TOSCo Project team presented the TOSCo concept at the SAE Government/Industry Meeting and the TOSCo System and Simulation Results at the SAE World Congress.

3.6 Implement CACC in Test Vehicles

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 the existing Adaptive Cruise Control (ACC)-equipped vehicles. Testing in this task verified correct operation of the CACC vehicle system.

3.7 CACC Comparative Performance Testing

The objective of the CACC Comparative Performance Testing Task was to establish relative performance comparison between CAMP and FHWA CACC vehicles and facilitate technical dialogue on application designs and prototype vehicle architectures.

During the third quarter, the TOSCo Project Team developed a plan for CACC testing, refined test cases and data elements and prepared for testing at a proving ground in October 2018.Test scenarios included scenarios developed by both CAMP and FHWA.

Demo Scenario: String Stability CAMP Scenario

- ACC & CACC with multiple speed ranges:
  - Accelerate to 55 mph, decelerate to 30 mph
  - Accelerate to 55 mph, decelerate to stop
  - Accelerate to 60 mph, decelerate to 25 mph
- Multiple deceleration values
  - Moderate: -2.5m/s/s
  - Moderate+: -3.0m/s/s
- Time Gap of 0.6s, 1.0s, 1.5s

Demo Scenario: String Stability FHWA Scenario

- ACC & CACC with single speed range
  - Accelerate to 60 mph, decelerate to 45 mph
- Single deceleration value
  - Moderate: -2.5m/s/s
- Time Gap of 0.6s, 1.0s

The TOSCo Project Team executed the test plans defined to evaluate string stability in columns of vehicles under automated longitudinal control during the fourth quarter of the year. Testing was performed at FT Techno of America's Proving Ground in Fowlerville, Michigan (FTTA) and at the US Army's Aberdeen Test Center in Maryland (ATC). FTTA testing used the CAMP's ad hoc CACC system and testing at ATC used FHWA's vehicle platooning system. Each round of testing executed both CAMP and FHWA defined string stability tests and collected a previously agreed upon set of common performance parameters.

During the first quarter of 2019, the TOSCo Project Team prepared data files, shared the data files with FHWA and began drafting the CACC Interim Report. The CACC Interim Report was completed and submitted to the FHWA on June 28, 2019.

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

4 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.

4.1 CADS Collaboration Planning

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 third quarter of 2018, the CADS Project Team participated in the FHWA National Dialogue on Automation listening sessions on Digital Infrastructure and Data and on Freight to gather stakeholder input. In the fourth quarter of 2018, the CADS Project Team participated in the FHWA National Dialogue on Automation listening sessions on Operations and on Infrastructure Design and Safety to gather stakeholder input. The team presented the draft CADS-Improved Freeway Mobility (IFM) ConOps to the IOO/OEM Forum – Connected Automation Work Group and integrated reviewer's comments as well as initiated a draft project proposal to investigate CADS-IFM through modeling and analysis of system implementation on a real-world corridor in the first quarter 2019. The CADS Project Team worked to identify partners interested in participating in the follow-on IFM research project and continued to develop a draft proposal for Phase 1 IFM research in the second quarter of 2019.

4.2 CADS Roadmap Review

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. During the third quarter of 2018, the team met with FHWA to review and discuss the DOT's current draft roadmap for CAV research. In the fourth quarter of 2018, the CADS Project Team prepared an overview of materials for use in a stakeholder outreach presentation which was presented to the IOO/OEM Forum Meeting in Washington, D.C. on January 29, 2019.

4.3 Improved Freeway Mobility

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 third quarter activities of 2018, the CADS Project Team held discussions with FHWA staff to obtain an overview of the results from CAV benefits modeling projects completed to date, held a concept framing discussion with FHWA staff and the project's systems engineering support contractor to initiate work on a high-level ConOps, and initiated dialogue with key research providers regarding the applicability of existing simulation tools to the development of a Freeway Mobility ConOps. In the fourth quarter activities of this task, the CADS Project Team developed a draft high-level ConOps describing CADS-IFM for discussion with FHWA staff that was reviewed during the first quarter of 2019. The team also initiated work on a Preliminary Hazard Analysis of CADS-IFM which carried into the first quarter of 2019.

5 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 project is divided into two phases. Phase I will lay a technical foundation for the EDCM concept by leading coordination and planning with our 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.

In Phase 2 of the project, Phase I will be expanded by building the additional functionality required to support the general EDCM Concept of Operations (ConOps) and system requirements. The resulting EDCM system will be combined with custom applications features to support QA / QW and Connected Work Zone (CWZ) applications in test vehicles containing the equipment, interfaces and functionality required to demonstrate the EDCM functionality through QA / QW and CWZ applications scenarios.

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. The project started May 26, 2019 with the project kickoff on June 17, 2019. Since the project started near the end of the period of performance for this report, there are no significant accomplishments to report.

6 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. This project started March 1, 2019.

Note: the IOO/OEM Forum and SAE Standards tasks were previously reported under the Program Administration Project during the period of July 1, 2018 through February 29, 2019. These outreach tasks were transferred to the Stakeholder Engagement and Outreach Project beginning March 1, 2019. The following activities occurred during the period of March 1, 2019 and June 30, 2019 as part of the Stakeholder Engagement and Outreach Project.

6.1 IOO/OEM Forum Outreach

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 (CVPFS) for implementation and verification support of infrastructure-side connected vehicle system elements.

6.1.1 Reduced Speed / Work Zone Warning Working Group

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. The group tracked the progress of the work zone mapping software toolchain developed under the CAMP V2I Safety Applications (V2I-SA) Project. The toolchain was deployed as part of the I-35 smart work zone initiative in Texas.

The mapping toolchain was also provided to Saxton Transportation Operations Laboratory (STOL) for integrating into the mapping toolset with the intersection mapping tool developed by Leidos at STOL.

Work was also completed on a preliminary Model Concept of Operations which described an Infrastructure System to Support the Reduced Speed Zone Warning – Lane Closure Application.

6.1.2 SPaT/RLVW Working Group

The V2I-SA 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. The Working Group developed the Clarifications for Consistent Implementations (CCIs) document for the Connected Signalized Intersections (CSI) applications for national interoperability. The document focuses on providing clarifications and

guidance for implementing standards in a consistent manner for SPaT, SAE J2735 Map Message (MAP) and optional Radio Technical Commission for Maritime Services (RTCM) message data content for transmission for improved interoperability between production vehicles and deployed intersections. The document addresses known ambiguities in the standard (SAE J2735) for SPaT and MAP message including comments and feedback from the IOOs and implementers. The CCI document was presented at the IOO/OEM face-to-face meeting at CAMP in Farmington Hills, Michigan on April 29, 2019.

Verification of SPaT/MAP message transmission for the RLVW application was initiated along three intersections along Halsted Road near 11 Mile Road in Farmington Hills, Michigan using the SPaT/MAP visualization tool. The verification tests showed anomaly in SPaT message in minEndTime data element for time to next phase. The value starts out as a large (>3000s) number and then resets to the correct value when the current phase has approximately 10s left before the phase change which coincides with the time remaining for the flashing “Don’t Walk” sign for the pedestrian crossing. All three intersections have the Siemens controller. This has been notified to the Road Commission for Oakland County (RCOC).

The SPaT/MAP verification tool was on loan to M-City for testing and identifying issues with their installations at 65 intersections in Ann Arbor, Michigan. Installers discovered some issue using the tool. M-City has not yet provided any other details about the operations status of any of the intersections.

6.1.3 Connected Automation Working Group

The TOSCo Principal Investigator (PI) continued to meet with the IOO/OEM Forum Connected Automation Working Group to present the TOSCo Project status and updated infrastructure requirements.

The CADS/IFM Project PI presented periodic updates to the Connected Automation Working Group, providing updates on the project progress and opportunities for IOO representatives to provide feedback on IFM Concept of Operations draft.

6.2 Support for Standards Development

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 American Associate of State Highway and Transportation Officials (AASHTO) for infrastructure-related standards development. An example of this support is the ongoing development of the SAE J2945/4 Road Safety Message (RSM) which is needed to support the deployment of infrastructure message enabling in-vehicle Reduced Speed Zone Warnings (RSZW) such as those developed under the V2I-SA Project.

Monthly meetings for the Traffic Signal Application (TSA) Technical Committee (TC) continued. In the June 2019 TSA TC meeting, the SPaT Challenge and the need for development of a CCI document to address ambiguity and clarification in the standard was presented. The TSA TC responsible for development of J2945/10 agreed to rename the document from “Recommended Best Practices for MAP-SPaT Development” to “MAP-SPaT Message Deployment – Intersection Operations” and included minimum performance requirements and implementation guidance as addressed in the CCI.

The committee was also responsible for the development of J2945/11 – Recommended Practices for Signal Preemption Message Development.

In the Infrastructure Applications (IA) TC, review for the J2945/3 for Weather was conducted for comment resolution. A 28-day ballot was held in April 2019. The development of the J2945/4 – Road Safety Message (RSM) that includes the Traveler Information Message and the CAMP-developed RSZW and CSW applications continued with a document walkthrough and a partial review was presented in March 2019 on draft version 16 which was issued in December 2018. The J2945/12 for traffic probe applications was in development.

Also in the IA TC, the mapping task force was formulated to review current mapping as defined in J2735 which is intersection-centric and does not address the need of RSZW, Curve Speed Warning (CSW) and future V2I applications. Additionally, the current mapping definition does not provide extensibility and support for large complex map message. The IA TC selected Jay Parikh to chair the mapping task force.

6.3 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 Connected Vehicle (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
AERIS	Applications for the Environment: Real-Time Information Synthesis
AMCD	Advanced Messaging Concept Development
ASN.1	Abstract Syntax Notation One
ATC	United States Army's Aberdeen Testing Center
BIM	Basic Information Message
BSM	Basic Safety Message
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
CAV	Connected Automated Vehicle
CCI	Clarifications for Consistent Implementations
CMC	Consortium Management Committee
ConOps	Concept of Operations
CSI	Connected Signalized Intersections
CSW	Curve Speed Warning
CV	Connected Vehicle
CVIR	Connected Vehicle-Infrastructure Research
CVPFS	Connected Vehicle Pooled Fund Study
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications

Acronym	Definition
EDCM	Event Driven Configurable Messaging Design & Development and Work Zone Queue Advisory / Queue Warning (QA/QW) Project
EVPW	Emergency Vehicle Priority Warning
FFTA	FT Techno of America's Proving Ground
FHWA	Federal Highway Administration
HARA	Hazard Analysis / Risk Assessment
I2V	Infrastructure-to-Vehicle
IA	Infrastructure Applications
IOOs	Infrastructure Owners and Operators
ITS	Intelligent Transportation Systems
MAP	SAE J2735 Map Message
MDOT	Michigan Department of Transportation
MMITSS	Multi Modal Intelligent Traffic Safety System
OEMs	Original Equipment Manufacturers
OTPs	Objective Test Procedures
PFS	Pooled Fund Study
PI	Principal Investigator
PoC	Proof-of-Concept
QA/QW	Queue Advisory / Queue Warning
RCOC	Road Commission of Oakland County
RLVW	Red Light Violation Warning
RSE	Roadside Equipment
RSM	Roadside Safety Message
RSU	Roadside Unit
RSZW	Reduced Speed/Work Zone Warning

Acronym	Definition
RSZW/LC	Reduced Speed Zone Warning / Lane Closure
RTCM	Radio Technical Commission for Maritime Services
RWMP	Road Weather Management Program
SAE	SAE International
SH	State Highway
SPaT	Signal Phase and Timing
SSGA	Stop Sign Gap Assistance
STOL	Saxton Transportation Operations Laboratory
SWIW	Spot Weather Impact Warning
TC	Technical Committee
TMC	Traffic Management Center
TMT	Technical Management Team
TOSCo	Traffic Optimization for Signalized Corridors (Project)
TSA	Traffic Applications Signal
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UCR	University of California Riverside
UMTRI	University of Michigan Transportation Research Institute
UPER	Unaligned Packed Encoding Rules
USDOT	United States Department of Transportation
Utah DOT	Utah Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I/I2V	Vehicle-to-Infrastructure / Infrastructure-to-Vehicle
V2I-SA	Vehicle-to-Infrastructure Safety Applications (Project)
VDOT	Virginia Department of Transportation

Acronym	Definition
VISSIM	Verkehr In Städten – SIMulationsmodell (from German, a Traffic Flow Simulation Package)
WANADA	Washington Area New Automobile Dealers Association
XML	eXtensible Markup Language

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

Toll-Free “Help Line” 866-367-7487
www.its.dot.gov

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