Development of Vehicle-to-Infrastructure Applications Program

Third Annual Report

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Final Report – August 31, 2017

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U.S. Department of Transportation
Federal Highway Administration

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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 third 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-Kia, Honda, Mazda, Nissan, Subaru, Volvo Truck, and VW/Audi. The period covered by the report is from July 1, 2016 through June 30, 2017. 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 Vehicle-to-Infrastructure Safety Applications, Eco-Approach / Eco-Departure at Intersections, Cooperative Adaptive Cruise Control Small-Scale Test and Advanced Messaging Concept Development. 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 third year of program operation. The period covered by the report is from July 1, 2016 through June 30, 2017. 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 third year. Information regarding work previously completed in the V2I Program can be found in the annual reports for the first two years of operations (Shulman and Geisler, 2015, Report No. FHWA-JPO-16-263; Shulman and Geisler, 2016, Report No. FHWA-JPO-16-480).

V2I Program Administration

Project Status: In Progress

Project Timeline: January 2014 – January 2019

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. Current V2I Consortium Participants are Ford, GM, Honda, Hyundai-Kia, Mazda, Nissan, Subaru, VW/Audi and Volvo Truck. This consortium represents a broad range of automotive perspectives that include both light vehicles and heavy truck as well as global viewpoints that include the U.S., Europe and Asia.
- 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
- Previously initiated and currently administer the following active projects:

- V2I Safety Applications (V2I-SA) Project
- CACC Small-Scale Test (CACC-SST) Project
- AERIS Eco-Approach and Eco-Departure Small-Scale Test and Evaluation (Eco A/D) Project

These projects are expected to enhance deployment of cooperative vehicle-infrastructure systems which will improve safety and mobility for drivers through improvements 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. In particular, the V2I Consortium 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: In Progress

Project Timeline: September 2014 – April 2018

The objective of the V2I-SA Project is 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 to Date

- Technical assessment of the candidate safety applications, identification of application selection criteria and a process for selecting for development, field test 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
- Development of the over-the-air Dedicated Short-Range Communications (DSRC) Basic Information Message (BIM) for CSW and RSZW/LC applications
- 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) and completion of objective testing. Documentation of application performance and analysis results
- Development of a process to automatically generate intersections 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's Safety Pilot Model Deployment (SPMD) 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 the current RLVW application and possible resolution of identified issues.
- 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 CV 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.

AERIS Eco-Approach and Eco-Departure Small-Scale Test and Evaluation Project

Project Status: In Progress

Project Timeline: June 2016 – September 2018

This project addresses near-term research needs on the Eco-Signal application development roadmap established by the AERIS Planning Study. The overall Eco A/D Project is planned in two phases. Phase 1 – Modeling and Analysis will select specific existing traffic corridors as potential Eco A/D deployment sites, model the overall operating environment and develop a system design using a simulation environment to evaluate potential benefits and risks. If the estimated potential benefits are promising and system risks manageable, Phase 2 – System Build and Test would implement and evaluate the system under controlled real-world conditions. The current active project work addresses Eco A/D Phase 1.

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 Infrastructure Owners and Operators (IOOs) for input
- Identified candidate corridors for Eco A/D 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 modelling 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 Eco A/D function is expected to operate

- Identified the high-level requirements that define the Eco A/D system operation. Conducted Review Meeting #3 with FHWA to present the simulation calibration, operating scenarios and system requirements.

Cooperative Adaptive Cruise Control Small-Scale Test Project

Project Status: In Progress

Project Timeline: June 2015 – July 2017 (Phase 1 Only)

Previous research conducted in the V2I Program's CACC Planning Project considered the feasibility of implementing CACC utilizing DSRC to expand the functionality of Adaptive Cruise Control (ACC). The conclusion of this work recommended a focused research effort to explore the viability and efficacy of this approach through prototyping and small-scale testing of a representative CACC system.

The CACC-SST Project is conducting the recommended research using a two-phase approach employing simulation tools and prototype evaluation to explore the feasibility and utility of providing CACC functionality as a DSRC-enabled evolutionary expansion of ACC.

Significant Accomplishments and Key Findings to Date

- Defined a vehicle architecture for the prototype ACC that will be used in the project. This architecture will evolve into the prototype CACC system later in the project.
- Completed the integration of the prototype ACC into the project's four test vehicles. The prototype platform was used in vehicle tests on the Virginia Smart Road to assess ACC performance and to study the involved sensors.
- Defined the simulation and vehicle test scenarios. These will form the basis for comparisons of the simulated ACC system with actual vehicle data collected using the prototype ACC on a test track.
- Defined the simulation environment architecture and the scope and complexity of the simulation models. Implemented the hardware and software for the simulation environment.
- Executed the test scenarios on the Virginia Smart Road to assess the performance of the prototype ACC system
- Evaluated data recordings from the testing with regards to sensor performance and overall ACC system performance
- Defined an algorithm architecture for the CACC prototype platform, identifying the relevant software modules to be implemented and tested
- Specified the algorithms and concepts for the software modules required for all three CACC software versions studied in the project
- Implemented all three versions of the CACC software into the simulation environment
- Completed a Hazard Analysis and Risk Assessment (HARA) for the identified CACC function
- Evaluated algorithm performance and demonstrated improvements in overall system reaction time and string-stability
- Developed a set of candidate performance requirements for CACC

- Identified additional required DSRC message data elements to support CACC and specified a BSM extension
- Developed recommendations for standardization and for future CACC research efforts

Advanced Messaging Concept Development Project

Project Status: Completed

Project Timeline: July 2015 – June 2017

The objective of the Advanced Messaging Concept Development (AMCD) Project was to evaluate the ability of connected vehicles to generate, and infrastructure to collect, BSM, Probe Data Message (PDM), and Basic Mobility Message (BMM) alternatives using cellular and DSRC communications under simulated data message control schemes. This effort included emulating elements of Dynamic Interrogative Data Collection (DIDC) control, where applicable, in real-world driving conditions for non-safety-critical applications. Technical work on this project has been completed.

Significant Accomplishments and Key Findings to Date

- Reviewed FHWA's communications research projects including simulation work on the DIDC concept and adapted the project's work plan accordingly
- Developed the detailed project test plan and reviewed it with FHWA
- Implemented the proposed system architecture in hardware and software and successfully completed bench testing
- Developed prototype vehicles for testing on the Virginia Smart Road
- Completed prototype testing of BSM and BMM on the Virginia Smart Road
- Briefed FHWA staff on Prototype Test Data and Full-scale Test Plan updates
- Completed integration of PDM functionality into prototype vehicles
- Completed full-scale testing of the BSM, PDM and BMM on the Virginia Connected Corridor (VCC) in Northern Virginia
- Provided a live demonstration of system functionality for FHWA staff
- Delivered Data Documentation and Prototype and Full-scale Test Data to FHWA
- Briefed FHWA regarding Data Analysis from Full-scale Test
- Reviewed the draft FHWA report – ITS Standards for the Data Capture Management Program and provided comments
- Delivered a report to FHWA on Recommendations to USDOT for Consideration by Standards Organizations
- Provided the project Final Briefing to FHWA
- Submitted the project Final Report to FHWA for review

1 V2I Program Administration

This document presents the Third 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 the report is from July 1, 2016 through June 30, 2017. 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 overall program is being 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-Kia, 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 bi-weekly 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 Advanced Messaging Concept Development (AMCD) Project was completed during the reporting period. Three projects are currently underway. These projects are:

- V2I Safety Applications (V2I-SA) Project
- Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Approach and Eco-Departure Small-Scale Test and Evaluation (Eco A/D) Project
- Cooperative Adaptive Cruise Control Small-Scale Test (CACC-SST) Project

Summaries of the activities and accomplishments within these projects are contained in the following sections of 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.

Several deliverables were prepared and submitted to FHWA as part of the work completed in the Program Administration Work Order during the past year. These involved the following items:

- 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 29, 2016, October 31, 2016, January 30, 2017 and April 28, 2017.
- Quarterly Progress Briefings, providing a presentation to FHWA of the work performed in the preceding quarter. Quarterly Progress Briefings were completed on July 27, 2016, October 27, 2016, February 8, 2017 and May 18, 2017.
- 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.
- The Second Annual Report for the V2I Program

Information regarding work previously completed in the V2I Program can be found in the annual reports for the first two years of operations (Shulman and Geisler, 2015; Report No. FHWA-JPO-16-263; Shulman and Geisler, 2016, Report No. FHWA-JPO-16-480).

2 Vehicle-to-Infrastructure Safety Applications Project

The V2I-SA Project started on September 15, 2014 and is scheduled to run through April 30, 2018. The objective of the V2I-SA Project is 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 are 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 is expected to run throughout the project. During the third year of program operations, outreach efforts in the V2I-SA Project included demonstrations of the three safety applications developed in the project and interactions with SAE, the Infrastructure Owners and Operators / Original Equipment Manufacturers (IOO/OEM) Forum and one of the USDOT Connected Vehicle (CV) Pilot sites.

2.1.1 Demonstrations of Safety Applications

The demonstrations of the safety applications were conducted on January 24-25, 2017 as part of the CV technology events associated with the 2017 Washington, DC Auto Show. Parking lot 7 at RFK Stadium served as the demonstration site for this event. Over 125 people participated, representing governmental agencies, the media and the automotive industry. The event format consisted of an introductory presentation followed by ride-along demonstrations of the CSW, RLVW and RSZW/LC applications in scenarios designed to showcase their features. Planning for the demonstrations began in July 2016. The activities undertaken to prepare for the event consisted of:

- Regular discussions with FHWA and the Washington Area New Automobile Dealers Association, sponsor of the Washington DC Auto Show, regarding the demonstration organization, logistics, and coordination with outside organizations

- Working with suppliers to prepare the detailed plans and specific scenarios to present. Included in this effort were a facility visit to identify a preliminary layout and demonstration setup.

- Planning the logistics for guest arrival, check-in and transit through the various parts of the demonstration

- Development of a website for registration and scheduling of USDOT and V2I Consortium guests to the demonstrations

- Conducting "dry runs" at RFK Stadium to refine the scenarios used and to provide practice runs for the demonstration drivers to become familiar with scenario execution
- Development of a an online participant survey to gauge efficacy of the demonstrations

2.1.2 Outreach to Infrastructure Owners and Operators

The V2I Consortium participated in discussions with the Tampa Hillsborough Expressway Authority (one of the USDOT's CV Pilot sites) regarding the V2I Safety Applications for their pilot program. This meeting was held on August 3, 2016.

On September 22-23, 2017, a group of IOOs and OEMs met with representatives from the American Association of State Highway and Transportation Officials (AASHTO) and FHWA to organize a forum in which information could be exchanged to support the future deployment of V2I and Infrastructure-to-Vehicle (I2V) applications. Since the forum's inception, the V2I Consortium has participated in the group's ongoing initiatives. In addition, the Consortium is also participating directly in three of the forum's working groups, established following the formation of the forum. The activities surrounding these groups are summarized below.

2.1.2.1 Reduced Speed / Work Zone Warning Working Group

Monthly Reduced Speed / Work Zone Warning (RSZW) Working Group meetings were held via online meetings. Technical work took place to coordinate input to SAE regarding the proposed structure and content of the Basic Information Message (BIM). The Virginia Department of Transportation provided background information on their Connected Vehicle Enhanced Work Zone Project as it relates to assessing and reporting worker presence information. Also during the period, the V2I-SA Project shared preliminary scope and timing information on the RSZW pilot testing efforts the project is conducting in conjunction with state Departments of Transportation (DOTs) in Michigan and Texas.

2.1.2.2 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 is currently being led by the V2I-SA Project Principal Investigator (PI). In June 2016, the V2I-SA team completed a document describing the process for verifying a SPaT implementation at an intersection. Discussion with the IOOs is ongoing to define the process for sharing the document with stakeholders, and for updating the document in the future. As IOOs begin to bring SPaT intersections online and begin to use the document to verify their installations, the intent is to capture the "lessons learned" and incorporate them into appendices to the verification document. Additionally, the V2I Consortium continued to participate in the SPaT Challenge resource team.

2.1.2.3 Connected Automation Working Group

The Eco A/D Project PI interacted with the IOO/OEM Forum's Connected Automation Working Group monthly to brief the group on progress made in the Eco A/D Project. The PI notified the group that documentation regarding operating scenarios and system requirements developed during the CAMP Eco A/D Project will be shared with the group in August 2017 to gain IOO perspective and insights.

2.1.3 Support for SAE Standards Development

Throughout the third 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. As part of these interactions, a presentation was made to the SAE DSRC TC on

May 3, 2017 to convey BIM information for standards work in J2945/4 (DSRC Messages for Traveler Information Message (TIM) and BIM Delivery). In addition, a BIM document, containing technical materials for standards consideration, was completed and submitted to the technical editor of J2945/4 and the DSRC TC members for review and comment. The material was submitted on May 31, 2017. As the third year of operations closed, action by the SAE DSRC TC was pending.

2.2 Testing

Activities in this task focused on the continued analysis of data for the RLVW, CSW and RSZW/LC applications that was collected during the previous reporting period. Revisions to the applications were implemented based on the testing results. The key outcomes from this effort are noted below.

For the RLVW application:

- Out of the 81 test runs conducted for ten test scenarios, 62% were successful runs that generated expected outcomes. The unsuccessful test runs were due to issues related to signal phase synchronization with the start of the test runs and improper map matching for a lane with permissible multiple movements.
- The algorithm was refined to support a single lane that can be associated with two signal phases (i.e., one for a straight movement and another for a right turn movement). The lane mapping in such a case is associated with the vehicle turn signal status for predicting the driver's intent. The updated application was re-tested on September 15, 2016. During the testing, a software issue was discovered which was subsequently resolved.
- The RLVW application was re-tested on October 6, 2016 at the University of Michigan's test facility. Test conditions and outcomes of the tests were:
  - A total of 44 test runs were conducted for 11 test scenarios, consisting of one primary and two secondary sets of scenarios
  - The primary set of scenarios validated the updated algorithm to support multiple signal phases associated with multiple movements permitted from a single lane
  - The two secondary sets of scenarios were tested to ensure that the updated algorithm had not inadvertently affected the performance of other test cases
  - All conducted tests runs were successful and generated expected outcomes
- The turn prediction algorithm was further enhanced by setting threshold limits for acceleration / deceleration. The enhancement improved prediction of driver intent based on vehicle acceleration / deceleration in the absence of turn signal activation such that a slight variation in vehicle speed due to coasting is now not considered as vehicle accelerating or decelerating.

For the CSW application:

- Out of 89 test runs conducted for six test scenarios, 83% were successful runs that generated expected outcomes. The unsuccessful test runs generated either a late Inform or a late Warning. Late Informs were generated due to delayed map matching of the approach lane caused by incorrect placement of cones. The late Warning was generated when vehicle speed was marginally higher than the computed maximum speed (Vmax) for the test.

- The algorithm was updated to address late Warning when vehicle speed is less than 11 mph higher than the computed Vmax. The application was re-tested on September 15, 2016 at the University of Michigan test facility. The data collected during the tests were subsequently analyzed. Test conditions and outcomes of the tests were:
  - Conducted 12 test runs for one test scenario at three different vehicle speeds: at and below the computed Vmax for the curve, slightly above the computed Vmax (up to 11 mph above) and well above the computed Vmax (more than 11 mph above)
  - All test runs conducted were successful and generated expected outcomes

For the RSZW application:

- Eighty-two test runs, across five test scenarios with approach speeds of 45 mph and 70 mph, were conducted
- All test runs generated Informs and Warnings within prescribed range, including the suppression of the Warnings for a lane closure based on the vehicle turn signal indicator. No anomalies were identified in the test analyses.

The work in this task has been completed.

2.3 Feasibility of Accommodating Actuated Traffic Signals

The current RLVW implementation developed in this project is designed to support pre-timed (fixed) signal timing values where signal operations are not based on detection. Pre-timed signal controllers encompass a significant percentage of the traffic signal locations in the U.S. This task, initiated in July 2016, involved a feasibility study to identify the scope of work needed to incorporate actuated traffic signals into the RLVW application.

A series of three working meetings were held to discuss actuated traffic signal operations and assess the implementation of the RLVW application. The working meetings were conducted by the Texas Transportation Institute (TTI) in conjunction with the project's Technical Management Team (TMT). The meetings were attended by the V2I-SA Project representatives from the FHWA, TMT, TTI and other project suppliers. The purpose of the first two working meetings was to gain a better understanding of actuated traffic signal concepts, technical characteristics and the range of operational features available from signal controller suppliers. The objective of the final working meeting was to discuss the concept of traffic signal preemption by emergency vehicles and analyze the impact on the current RLVW application. Following the discussions in this task, it was determined that since the RLVW algorithm for warning the driver is based on the onset of the yellow phase, there was minimal or no impact from actuated traffic signals on the current application implementation.

A technical summary of the work completed in the task was presented to FHWA during a briefing held on February 13, 2017. This task is complete.

2.4 On-Road Engineering Tests of Curve Speed Warning and Reduced Speed Zone Warning Applications

In this task, the CSW and RSZW/LC applications were evaluated through engineering tests conducted on selected public roads in Southeast Michigan. The task began in September 2016 and concluded in

February 2017. The test sites were selected in conjunction with the Michigan Department of Transportation (MDOT).

For the CSW tests, seven freeway curves were identified and mapped. These curves had varying radii s-curves. The CSW application was tested during October 2016 under varying traffic conditions on five out of the seven selected curves using two test vehicles. The two curves dropped from testing have a large radius of curvature and the computed Vmax is well over the posted speed limit, precluding testing at these locations.

The CSW application performed as expected in all five of the curves used in testing. The application correctly generated Informs and Warnings for vehicle speeds above the computed Vmax for the curve. Due to varying traffic conditions, test vehicles could not be driven move than 11 mph above the computed Vmax on the curves. In the instances in which the testing speed was constrained, the application generated only the Warning 1, as expected.

For the RSZW/LC application, MDOT identified work zones on northbound and southbound I-75 in the Detroit metropolitan area. The identified work zones were available for testing through mid-December 2016 when road construction was suspended for the winter. In mid-October 2016, the TMT updated an MDOT-provided Roadside Unit (RSU) with the application, work zone map and BIM for the test. In late November, the programmed RSU was installed on a trailer and set up at the work zone. RSZW application testing was conducted on December 1st and December 7th, just before removal of the work zone for the winter. Three test vehicles were used and data was collected for nine test scenarios. The analysis of the logged data indicated the work zone application worked as expected and provided appropriate lane closure and work zone speed warnings for all tests.

A technical summary of the work completed in the task was presented to FHWA on February 13, 2017. Work in this task is complete.

2.5 Work Zone Mapping

The goal of this task is to develop a dynamic mapping technique to enable near real-time work zone mapping for the RSZW/LC application. The developed mapping technique will be tested in live work zones in Southeast Michigan during the 2017 road construction season. The task started in April 2017. In the work completed to date, a project test vehicle was driven in a Detroit-area work zone on I-75 to collect vehicle path data in both the northbound and southbound directions. Processing software is currently being developed to create a work-zone map for use in the BIM from the collected vehicle path data. During future work in this task, software-generated work zone maps will be tested using the RSZW/LC application developed in this project to assess the effectiveness of the mapping process.

3 AERIS Eco-Approach and Eco-Departure Small-Scale Test and Evaluation Project

This project addresses near term research needs on the Eco-Signal application development roadmap established by the previously completed AERIS Planning Project. The Eco A/D Project is a joint effort between the V2I Consortium, TTI, and the University of Michigan Transportation Research Institute (UMTRI). The project focuses on first identifying potential real-world test locations followed by establishment of a balanced set of vehicle and infrastructure user needs that will drive Eco A/D system performance requirements that result in desired functionality. To support these objectives, the V2I Consortium will conduct outreach activities with relevant IOOs. Work in this project was initiated on June 23, 2016.

3.1 Simulation Modeling and Performance Analysis

This task will lay the foundation for developing a simulation model of actual urban corridors that possess the environmental attributes important to the operation of an Eco A/D system, as identified by the project team.

3.1.1 Identify Potential Locations for Implementation

The project team identified a number of key corridor attributes and ranked them low, medium or high in importance. Using the list of attributes and the assigned priorities, the research partners then identified a number of low-speed and high-speed corridors that encompassed a majority of the medium- and high-priority attributes. The project team then reviewed video clips of the various candidates and chose a first and second option. Sites for the low-speed and high-speed corridors were then selected based on project team selections.

The outcome of this task was the subject of Review Meeting #1 held October 13, 2016 to discuss with FHWA the selection of Plymouth Road in Ann Arbor, Michigan between Dixboro Road and Barton Drive for the lower speed corridor and State Highway 105 in Conroe, Texas between Loop 336 and Lone Star Parkway for the higher speed corridor. This subtask is complete.

3.1.2 Characterize Simulation Environment and Traffic Flows

Work in this subtask focused on coding of roadway and intersection geometrics into VISSIM (a traffic simulation software package, Verkehr In Städten – SIMulationsmodell) and collection of travel times and speed information for calibration. Collection of traffic volume data and traffic and intersection movement counts was completed at the end of January 2017.

3.1.3 Calibrate the Simulation Environment

Activities in this subtask defined the details of the overall vehicle and infrastructure simulation environment to be used for both the low-speed and high-speed corridors. This work was completed and presented to FHWA during Review Meeting #3 on June 22, 2017.

3.2 System Architecture and Algorithm Development

The objective of this task is to establish the Eco A/D system architecture and develop the vehicle and infrastructure algorithms needed to support Eco A/D functionality. The architecture and algorithms will then be incorporated into the simulation environment discussed above.

3.2.1 Stakeholder Needs Definition

The Project Team undertook the identification of stakeholders that could potentially be affected by an Eco A/D function and endeavored to define their respective needs. Understanding stakeholder needs is important to determine the bounds in which the Eco A/D function needs to operate. These bounds can affect the design of the simulation environments used in the Eco A/D Project.

An initial list of stakeholder needs was prepared and discussed with IOOs to identify needed refinements. The list was shared with various members of the IOO/OEM Forum Connected Automation Working Group on December 16, 2016 with a follow-on meeting held December 22, 2016 with representatives of the Road Commission for Oakland Country (Michigan, RCOC). The discussions also provided a matrix of current challenges that could be addressed by Eco A/D, potential Eco A/D concepts that could address those challenges, and IOO-requested requirements for the Eco A/D concepts.

The following is a list of stakeholders for which a detailed list of stakeholder needs and system requirements that support stakeholder needs was created:

- AERIS-equipped vehicle driver (privately owned vehicle)
- Unequipped vehicle driver (privately owned vehicle)
- AERIS-equipped vehicle driver (commercial)
- Unequipped vehicle driver (commercial)
- Pedestrians (vulnerable / non-motorized road users)
- Traffic management center operator
- Municipal government (city / county officials)
- Transit operator
- Emergency responders
- Maintenance crews
- Heavy rail
- Signal controller methodologies (fixed / actuated / adaptive)

The list of stakeholder needs was presented and discussed at the IOO/OEM Forum meeting on January 26, 2017. FHWA was briefed on this material during Review Meeting #2 held February 8, 2017.

3.2.2 Scenario Definition

Work to develop test scenarios for use in the simulation environment to assess the performance of Eco A/D concepts was completed and presented to FHWA during Review Meeting #3 held June 22, 2017. A total of 32 base scenarios were identified that were contained within five operational categories. The scenarios will be used to assess the performance of Eco A/D concepts.

3.2.3 System Objectives and Functional Requirements

Work to develop overall system objectives and the functional requirements for the vehicle and infrastructure components of an Eco A/D system was completed and presented to FHWA during Review Meeting #3. The system objectives address six key elements: coordinated stop, coordinated travel and coordinated launch for the lead vehicle of a string and coordinated stop, coordinated travel and coordinated launch for members of a string. Functional requirements included vehicle-side as well as infrastructure-side requirements and are differentiated according to whether the vehicle is at the head of the string or a member of the string. CACC requirements established under a separate CAMP project have been incorporated into Eco A/D.

3.3 System Specifications and Hazard Analysis

The objectives of this task are to create and refine a CACC-enabled Eco A/D system specification, documenting the Eco A/D functionality developed and evaluated. A safety concept will also be developed for the proposed Eco A/D system that addresses both in-vehicle and infrastructure components. The overall Eco A/D system specification will be reviewed for potential hazards and functional requirements will be refined to mitigate risks on an ongoing basis throughout the project.

3.3.1 Hazard Analysis / Risk Assessment

The Project Team initiated work to develop the Hazard Analysis / Risk Assessment (HARA). The work being pursued leverages work accomplished in the CACC-SST Project (discussed in the next chapter). Four hazards have been identified and are being defined. The hazards identified are incorrect excessive acceleration, incorrect insufficient deceleration, incorrect excessive deceleration and incorrect insufficient acceleration.

3.4 Coordination and Outreach

Under this task the Project Team interacts with other relevant USDOT programs and projects in order to successfully execute the tasks and activities within Phase 1. Activities during the period included:

- Visited the Maricopa County, Arizona Traffic Signal Priority / Emergency Vehicle Preemption pilot deployment site in Anthem, Arizona to assess the suitability of incorporating the work into the Eco A/D Project. This pilot deployment addresses one element of the overall Eco A/D concept and has potential for incorporation.
- Attended a meeting sponsored by FHWA for OEMs and IOOs at Turner-Fairbank Highway Research Center in McLean, Virginia on September 22-23, 2016
- The Eco A/D Project PI met with members of the IOO/OEM Forum Connected Automation Working Group on December 16, 2016 to discuss stakeholder needs
- A meeting was subsequently held on December 22, 2016 with representatives of RCOC who met with the TMT to discuss a matrix of current challenges that could be addressed

by Eco A/D, potential Eco A/D concepts that could address those challenges, and IOO-requested requirements for Eco A/D concepts

- The Eco A/D Project PI met with members of the IOO/OEM Forum Connected Automation Working Group on January 19, 2017 to discuss stakeholder needs
- The list of stakeholder needs was presented to the IOO/OEM Forum on January 26, 2017 to gain feedback to finalize the list
- The Eco A/D Project PIs and UMTRI representatives met with traffic officials for the City of Ann Arbor on May 12, 2017 to discuss use of the Plymouth Road corridor for possible Phase 2 on-road testing. The presentation was well-received and plans to utilize the selected corridor for Phase 2 testing appear initially feasible.
- The Eco A/D Project PIs and TTI representatives met with elected officials for the City of Conroe, Texas on June 21, 2017 to discuss use of the State Highway 105 corridor for possible Phase 2 on-road testing. The presentation was well-received and plans to utilize the selected corridor for Phase 2 testing appear initially feasible.

3.5 Implement CACC in Test Vehicles

The objective of this task is to implement and debug the CACC algorithms developed in the simulation environment during the previous CACC-SST Project in at least two but no more than four of the existing Adaptive Cruise Control (ACC)-equipped project vehicles. Testing will be conducted to verify correct operation of the CACC vehicle system.

3.5.1 CACC Vehicle System Integration

The Project Team initiated work to implement and debug the CACC algorithms. A need for additional equipment in the form of media converters was identified early in the work due to a change in the DSRC radio output. The media converters were obtained and delivered to the supplier. This work will continue into the next reporting period.

4 Cooperative Adaptive Cruise Control Small-Scale Test Project

The CACC-SST Project was initiated on June 1, 2015. The overall objective of the CACC-SST Project is to perform the recommended research identified in the preceding CACC Project using a two-phase approach employing simulation tools and prototype evaluation to explore the feasibility and utility of providing CACC functionality as a DSRC-enabled evolutionary expansion of ACC. Only the initial phase of the CACC-SST Project has been awarded. It is scheduled to conclude in July 2017.

4.1 Field Test and Analysis of Empirical Data

The objectives of this task are to build the simulation environment required for algorithm development and to collect empirical data on ACC operation using test vehicles.

4.1.1 Exploratory Tests

The exploratory tests performed in this subtask involved vehicle characterization tests using the scenarios defined earlier in the project to obtain data to parameterize the simulation environment for the specific vehicles and sensors used in the project. The exploratory tests were completed in the prior reporting period, however, data analysis continued into the current period. On August 16, 2016, the final delivery of test data and analysis was provided by the Virginia Tech Transportation Institute. This step concluded the Exploratory Tests subtask. Since then, the project team conducted additional investigations of the test data to answer specific questions about sensor characteristics (e.g., regarding DSRC and radar sensor performance) to improve the simulation environment.

4.1.2 Simulation Setup

A simulation environment was used to study different implementation options for CACC in the Algorithm Development, Simulation and Specification work in the project (see next section). The implementation of the simulation environment was initiated in the previous year of project operations and continued into the current reporting period. Challenges encountered in the integration of the required software components and the interfacing with the development environment that will host the CACC algorithms were resolved during the third quarter of 2016. Testing of the simulation environment followed and was completed in October 2016. Small refinements to the simulation environment and bug fixes were still necessary and completed as needed. This subtask was designated as completed in October 2016 because the simulation was providing its functionality to assess the CACC algorithm.

4.2 Algorithm Development, Simulation and Specification

In this task, three versions of the CACC software were defined, which built on top of each other and provided CACC with increased features. This development approach allowed for the comparison of different CACC configurations. The three CACC software versions were tested and refinements were incorporated throughout the process.

During the second half of 2016, the first CACC software version was implemented and tested based on the developed specification. The first CACC software version was characterized during various simulation runs. Results from comparing the CACC software to baseline simulation runs with ACC software were promising and indicated the anticipated performance improvements.

A HARA of CACC, initiated during the prior reporting period, was also completed. The project team developed the CACC safety concept that, through algorithm modifications, aimed to mitigate the hazards identified in the HARA. The safety concept was refined and was reviewed with FHWA during a meeting on February 8, 2017.

In parallel with the testing of the first software version, the specification for the second software version was finalized and the implementation of this version was completed. Testing was conducted during the end of 2016 and the first quarter of 2017.

Subsequently, the features for the third and final software version were defined and the specification was completed. After collecting additional data as validation for the specification, the implementation of the third software version started in early 2017. Testing was conducted with the third software version during the first half of 2017. Overall, the project team conducted and analyzed more than 600 simulations, focusing on different scenarios to assess algorithm performance. Simulations to assess the string-stability and reaction times of the system were also conducted. The results showed the expected benefits. Additionally, simulations were conducted to compare the simulation results with actual vehicle test results. A strong consistency across results was identified, indicating a good parameterization of the simulation environment.

Improvements made to the simulation environment during the execution of this task removed an initial simulation limitation of five vehicles and subsequently allowed more complex scenarios be studied. An infrastructure-supported-merging algorithm was evaluated and correct functionality was demonstrated.

Assessments indicated that the overall CACC algorithm performed as intended and that the anticipated performance improvements were realized. The evaluation led to the definition of a formal DSRC message extension to support CACC. This extension will be tested as part of future work in the Eco A/D Project currently underway. A contract with a supplier was set up to update the software of the existing DSRC radios in the project test vehicles so that it supports the message extension.

While assessing simulation results, it was noted that minimum performance requirements for CACC needed to be established. This is necessary to ensure proper cooperation between multiple CACC vehicles from different manufacturers. As a starting point for a continuing discussion about standardization and requirements, the project established a list of candidate minimum performance requirements.

The performance evaluation results, as well as recommendations for future developments, were compiled and incorporated into the project final report. Stakeholder outreach documents (i.e., a paper for the Transportation Research Board 2018 Annual Meeting and a presentation on standardization needs for CACC) were created. Publication reviews for all three documents were initiated and will continue into the next reporting period.

This task was completed in June 2017.

4.3 Planning for Phase 2

Planning for Phase 2 of the project was initiated in the prior reporting period. During the third quarter of 2016, a proposal for CACC-SST Phase 2 was developed. The project team identified relevant goals and technical tasks, issued Requests for Proposals to suppliers and developed a technical proposal as well as a cost proposal. With the delivery of the Phase 2 proposal to FHWA in November 2016, this task was complete.

5 Work Order 7 - Advanced Messaging Concept Development Project

The AMCD Project final briefing was provided in April 2017 and technical work was completed in June 2017 with the submission of the project final report. The objective of the AMCD Project was to evaluate the ability of connected vehicles to generate, and infrastructure to collect, Basic Safety Message (BSM), Probe Data Message (PDM), and Basic Mobility Message (BMM) alternatives using cellular and DSRC communications under simulated data message control schemes. This effort included emulating elements of Dynamic Interrogative Data Collection (DIDC) control, where applicable, in real-world driving conditions for non-safety-critical applications.

5.1 Integration Validation Research

The Integration Validation Research Task provided for field-testing of BSM, PDM and BMM message set alternatives / concepts under simulated data message control schemes in two iterative phases on Virginia Connected Corridors (VCC) locations on the Smart Road in Blacksburg, Virginia and in Fairfax County, Northern Virginia.

5.1.1 Prototype Test Preparation

Work to implement the BSM and BMM concepts was completed in the previous reporting period. Software difficulties related to implementing the full PDM concept were resolved in October 2016. With the resolution of the PDM software issues, the preparation work for the prototype tests was completed.

5.1.2 Prototype Test Execution

Prototype testing and data collection for the BSM and BMM concepts was successfully completed in September 2016. PDM prototype validation and data collection were delayed pending resolution of software performance issues. PDM prototype testing and data collection was completed in November 2016. Work on this subtask is complete.

5.1.3 Full-Scale Test Preparation

Ten vehicles were prepared for full-scale testing of the messaging concepts. Final validation of the prototype test vehicles was completed in November 2016. RSU installation along the VCC in Northern Virginia was also completed in November 2016. This subtask is complete.

5.1.4 Full-Scale Test Execution

Full-scale testing was completed in November 2016 along with a live demonstration of system functionality at the Turner Fairbank Highway Research Center. Full-scale test scenarios exercised the messaging schemes with data from the 10 vehicles stored on the VCC Cloud for later analysis. Testing on the VCC was performed during different times of the day across light and heavy traffic conditions. During testing, an experimenter used the VCC Monitor Application to orchestrate vehicle and messaging activities from controlled testing to more natural vehicle traversals, during which time the drivers could choose their path and actions around the test bed. This allowed the collection of a controlled dataset for specific analysis while also providing an indication of how the system may operate under normal conditions. Work on this subtask is complete.

5.1.5 Data Analysis and Presentation

Data documentation and test data from the Prototype and Full-scale testing were delivered to FHWA. A briefing on Data Analysis from Full-Scale Test was provided to FHWA in January 2017. Work on this subtask is complete.

5.2 Cross-Cutting Standards Support

This task provides for assistance to the Dynamic Mobility Application Program in supporting the activities of the ITS Standards Program, including attendance at select Standards Development Organization (SDO) working meetings and participation in relevant standards development efforts.

5.2.1 Standards Support

Comments were provided in briefing format in March 2017 on the implications of lessons learned from executing the AMCD Project relevant to topics presented in the FHWA draft report "ITS Standards for the Data Capture and Management Program – Design Content." Work under this subtask is complete.

5.2.2 Analysis of Potential ITS Standards Changes to Support Dynamic Mobility Applications

Comments were provided in report format in March 2017 summarizing recommendations to USDOT for consideration by the SDOs resulting from executing the AMCD Project. Work on this subtask is complete.

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
BIM	Basic Information Message
BMM	Basic Mobility Message
BSM	Basic Safety Message
CACC	Cooperative Adaptive Cruise Control
CACC-SST	Cooperative Adaptive Cruise Control Small-Scale Test (Project)
CAMP	Crash Avoidance Metrics Partners
CMC	Consortium Management Committee
CSW	Curve Speed Warning
CV	Connected Vehicle
CVIR	Connected Vehicle-Infrastructure Research
DIDC	Dynamic Interrogatory Data Capture
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
Eco A/D	Eco-Approach / Eco-Departure
EVPW	Emergency Vehicle Priority Warning
FHWA	Federal Highway Administration
HARA	Hazard Analysis / Risk Assessment
I2V	Infrastructure-to-Vehicle
IOO	Infrastructure Owners and Operators
ITS	Intelligent Transportation Systems

Acronym	Definition
MAP	SAE J2735 Map Message
MDOT	Michigan Department of Transportation
OEMs	Original Equipment Manufacturers
OTPs	Objective Test Procedures
PDM	Probe Data Message
PI	Principal Investigator
RCOC	Road Commission for Oakland County (Michigan)
RLVW	Red Light Violation Warning
RSU	Roadside Unit
RSZW	Reduced Speed Zone Warning
RSZW/LC	Reduced Speed Zone Warning / Lane Closure
RWMP	Road Weather Management Program
SAE	SAE International
SDO	Standards Development Organization
SPaT	Signal Phase and Timing
SPMD	Safety Pilot Model Deployment (Project)
SSGA	Stop Sign Gap Assistance
SWIW	Spot Weather Impact Warning
TC	Technical Committee
TIM	Traveler Information Message
TMT	Technical Management Team
TTI	Texas Transportation Institute
UMTRI	University of Michigan Transportation Research Institute
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I/I2V	Vehicle-to-Infrastructure / Infrastructure-to-Vehicle

Acronym	Definition
V2I-SA	Vehicle-to-Infrastructure Safety Applications (Project)
VCC	Virginia Connected Corridor
VISSIM	Verkehr In Städten – SIMulationsmodell (German, a Traffic Flow Simulation Package)

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