Development of Vehicle-to-Infrastructure Applications Program

Second Annual Report

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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 second year of the "Development of Vehicle-to-Infrastructure Applications (V2I) Program." Participating companies in the V2I Consortium during this period were FCA US LLC, Ford, General Motors, Hyundai-Kia, Honda, Mazda, Nissan, Subaru, Volvo Truck, and VW/Audi. The period covered by the report is from July 1, 2015 through June 30, 2016. 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 investigated were Cooperative Adaptive Cruise Control (CACC), Vehicle-to-Infrastructure Safety Applications, Road Weather Management Connected Vehicle-Infrastructure, Eco-Approach / Eco Departure at intersections 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 second year of program operation. The period covered by the report is from July 1, 2015 through June 30, 2016. 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 second year of program operations. Information regarding work previously completed in the V2I Program can be found in the first annual report titled “Development of Vehicle-to-Infrastructure Applications Program First Annual Report” (Shulman and Geisler, 2015; Report No. FHWA-JPO-16-263).

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 FCA US LLC, 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
  - Road Weather Management Program (RWMP) Connected Vehicle-Infrastructure Research (CVIR) Project – completed June 2016
  - Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Approach and Eco-Departure Planning Project – completed January 2016
- Initiated and currently administer the following active projects:

- V2I Safety Applications (V2I-SA) Project
- CACC Small-Scale Test (CACC-SST) Project
- Advanced Messaging Concept Development (AMCD) Project
- AERIS Eco-Approach and Eco-Departure Small-Scale Test and Evaluation (Eco A/D SST) 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 – March 2017

The objective of the Vehicle-to-Infrastructure Safety Applications (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 (RSZW) and Stop Sign Gap Assist (SSGA). The RLVW, CSW and RSZW applications were selected for development based on assessments conducted in the project and discussions with FHWA staff.

Significant Activities and Key Findings to Date

- Completed 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.
- Preparation of development plans for selected 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 documenting the initial test results
- Development of Objective Test Procedures (OTPs) and documenting application performance results and analysis
- Development of a process to automatically generate intersections maps (in SAE J2735 MAP format) 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 Program.
- Completed the demonstration of the RLVW, CSW and RSZW 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.

Road Weather Management Program Connected Vehicle-Infrastructure Research Project

Project Status: Completed

Project Timeline: May 2015 – June 2016

The objective of the Road Weather Management Program Connected Vehicle-Infrastructure Research (RWMP-CVIR) Project was to assess how weather, road condition and related vehicle data may be collected, transmitted, processed and used in road weather applications and services. This project was a joint effort between the V2I Consortium and the Virginia Tech Transportation Institute (VTTI).

Significant Activities and Key Findings to Date

- Identified road weather related variables of interest. The CAMP-VTTI team worked with FHWA to develop an understanding of the types of data that may be of interest to road weather research and applications and established a preliminary list of variables for use in assessing the availability of weather-related vehicle data elements on representative, high-volume, production vehicles.
- Identified vehicles that may be candidates for obtaining the desired road weather data for other ongoing FHWA RWMP research projects. The vehicles are high-production vehicles manufactured by the Participants in the V2I Consortium.
- Developed a high-level concept for a potential follow-on project for Dynamic Road Surface Mapping (DRSM) to support V2I communications-based safety applications. DRSM would crowdsource weather-related data from connected vehicles regarding road surface condition. Aggregated road surface condition data could be used to support in-vehicle-based safety systems as well as road weather maintenance operations.
- Provided the final project briefing on April 17, 2016 and delivered the RWMP Final Report for FHWA review on April 29, 2016. The final report was in publication review at the time this report was prepared.

AERIS Eco-Approach and Eco-Departure Planning Project

Project Status: Completed

Project Timeline: June 2015 – February 2016

The objective of the project was to identify information gaps, define technical and safety needs, and propose an evolutionary research plan for developing and evaluating Applications for the Environment: Real-time Information Synthesis (AERIS) Applications. This project was a joint effort between the V2I Consortium and the Texas Transportation Institute (TTI) in conjunction with the University of California Riverside and the University of Michigan Transportation Research Institute (UMTRI).

Significant Accomplishments and Key Findings to Date

- Completed the literature review. Completed work to examine the technical feasibility of prototyping Eco-Approach and Eco-Departure (Eco-A/D) applications and establishing a research plan to develop and evaluate potential concepts. This included the review of relevant background documents describing prior and ongoing Eco-A/D research and defining initial research topics in the following categories: (1) Eco-Concepts; (2) Vehicle Technical Issues; (3) Infrastructure Technical Issues; (4) Communications/Standards; (5) Human Factors; and (6) Performance Measures. This work established the foundation for future tasks, including refinement of an eco-signal application concept and developing a roadmap for future research.

- Completed definition of the Eco-Signal Application concept, assumptions and initial research questions. Working with the FHWA, a review of the AERIS Eco-Signal Operations: Operational Concept was conducted in this effort and over 200 assumptions were identified. These assumptions were combined with the key issues and knowledge gaps identified during the project and were prioritized by team members (high, medium, and low). The results of this analysis provided the assumptions, key issues and next steps that were used to define/refine a concept for an Eco A/D research plan.
- Completed a Research 'Road Map' to address Eco-Signal research needs, a research plan which explored the potential benefits of deploying an Eco A/D system as well as addressed the knowledge gaps identified in the prior work. The research plan is divided into three phases, near-, mid- and long term, covering a ten-year period.
- Completed assessment of transportation-related data sharing. This task examined potential issues associated with sharing transportation data originating from infrastructure operated by public agencies with private owner vehicle systems across jurisdictions. The research identified the various forms of data, both current and anticipated, that will require sharing across jurisdictions and investigated shortcomings that may limit the sharing of that data to facilitate advanced operations, including real-time data that will enable connected vehicle operations.
- Provided the final project briefing on January 28, 2016 and delivered the final report for FHWA review on January 22, 2016. The final report was in publication review at the time this report was prepared.

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

Project Status: In Progress

Project Timeline: June 2016 – February 2017

This project addresses near term research needs on the Eco-Signal application development roadmap established by the AERIS Planning Project completed by the V2I Consortium. The Eco-Approach and Eco-Departure (Eco-A/D) Small Scale Test Project is a joint effort between the V2I Consortium, TTI, and 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 infrastructure owner/operators.

Significant Accomplishments and Key Findings to Date

- Technical work under Phase 1 was initiated on June 132016, just as the reporting period for this report closed. As a result, activities completed during the period were limited to start up and project kickoff activities.

- Supplier selection for the initial portion of the project was completed in June 2016, establishing initial roles and responsibilities for TTI and UMTRI

Cooperative Adaptive Cruise Control Small-Scale Test Project

Project Status: In Progress

Project Timeline: June 2015 – February 2017 (Phase 1 only)

Previous research conducted in the V2I Program's Cooperative Adaptive Cruise Control (CACC) Planning Project considered the feasibility of implementing CACC utilizing Dedicated Short-Range Communications (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 Cooperative Adaptive Cruise Control – Small-Scale Test (CACC-SST) Project is performing 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. Implementation of the hardware and software needed to complete the simulation environment is underway.
- Executed the test scenarios on the Virginia Smart Road to assess the performance of the prototype ACC system
- 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 the first CACC software version

Advanced Messaging Concept Development Project

Project Status: In Progress

Project Timeline: July 2015 – April 2017

The objective of the Advanced Messaging Concept Development Project (AMCD) is to evaluate the ability of connected vehicles to generate and for the 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 includes emulating elements of Dynamic Interrogative Data Collection (DIDC) control, where applicable, in real-world driving conditions for non-safety critical applications.

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. Successfully completed bench testing.
- Developed prototype vehicles for testing on the Virginia Smart Road

1 V2I Program Administration

This document presents the Second 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 Agreement No. DTFH6114H00002. The period covered by the report is from July 1, 2015 through June 30, 2016. 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 Participants in the consortium are FCA US LLC, 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.

Two projects, initiated during the first year of the V2I Program, were completed in this reporting period. These are summarized later in the report and include:

- Road Weather Management Program (RWMP) Connected Vehicle-Infrastructure Research (CVIR) Project – completed June 2016
- Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Approach and Eco-Departure Planning Project – completed January 2016

Four projects are currently underway. These projects, also summarized later in the report, are:

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

The above projects 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. In particular, 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 the activities noted above, several deliverables were prepared and submitted to FHWA as part of the work completed in the Program Administration Work Order. 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 October 30, 2015, February 10, 2016, April 30, 2016, and July 30, 2016.
- Quarterly Progress Briefings, providing a presentation to FHWA of the work performed in active projects during the preceding quarter. Quarterly Progress Briefings were completed on August 5, 2015, October 21, 2015, January 28, 2016, and May 5, 2016.
- 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 (i.e., this report)

Information regarding work previously completed in the V2I Program can be found in the first annual report titled “Development of Vehicle-to-Infrastructure Applications Program First Annual Report” (Shulman and Geisler, 2015; Report No. FHWA-JPO-16-263).

2 Vehicle-to-Infrastructure Safety Applications Project

The Vehicle-to-Infrastructure Safety Applications (V2I-SA) Project started on September 15, 2014 and is scheduled to run through March 31, 2017. 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 (RSZW) 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.

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 second year of program operations, outreach efforts in the V2I-SA Project included presentations and status updates as follows:

- A presentation on RSZW application development progress was made at the V2I Deployment Coalition meeting on August 18, 2015
- Four presentations were made to the SAE Dedicated Short-Range Communication (DSRC) technical committee on the proposed Basic Information Message (BIM) (message structure, data elements, etc.), implementation of the BIM in the V2I-SA Project and the initial BIM testing results. The presentations were made on July 22, 2015, August 25, 2015, September 23, 2015 and February 18, 2016.

In addition, demonstrations of the three safety applications under development in the project were held on April 19-22, 2016 at a test track in Fowlerville, Michigan. Over 200 guests from the V2I Deployment Coalition, the USDOT's Connected Vehicle Pilot sites, the Smart City Challenge finalists, the Original Equipment Manufacturers (OEMs) and the USDOT attended the event. Planning for the demonstrations began in December 2015 and included the following activities:

- Regular discussions with FHWA for the overall event organization and coordination with participating organizations
- Preparing demonstration scenarios, application technology posters and informational materials for the demonstration guests as well as planning the facilities setup for the demonstrations and the logistics for guest check-in and onsite transportation
- Preparation of five additional test vehicles to expand the fleet of equipped vehicles used in the demonstrations to 12 (11 light vehicles and one heavy truck)

- Conducting "dry runs" at test tracks to refine the demonstration scenarios and to provide practice runs for the demonstration drivers to become familiar with scenario execution

2.2 Application Development

The work in the Application Development task focused on the development of the three safety applications selected as part of the work performed earlier in the project (i.e., RLVW, CSW, and RSZW). During the year, work continued in this task and efforts were directed toward the following activities:

- Working in conjunction with project suppliers, continued development and refinement of the application in the following areas:
  - Relevance Algorithm to determine "relevance" of the upcoming event (signalized intersection, curve, work/school zone) based on the vehicle approach
  - Map Matching Algorithm to determine the vehicle position with respect to the map of the event. The determination of vehicle position either at the road-level when Global Positioning System (GPS) correction is not available or at the lane-level when the correction is available as required by the application.
  - Warning Level Assessment Algorithm to determine appropriate level of warning to the driver based on various inputs such as vehicle speed, posted speed, distance from the event, requirements for the event, vehicle dynamics, etc.
  - Inform/Warning Generation Algorithm to generate appropriate "Inform/Warning" for issuing to the driver on the Driver-Vehicle Interface (DVI). Inform messages advise the driver of an upcoming event (e.g., signalized intersection, curve, work/school zone). "Warning 1" messages advise the driver of a possible violation or potential need to take action while "Warning 2" messages advise the driver to take an immediate action.
- Development and implementation of the BIM for the CSW and RSZW applications
- Development of requirements for application performance, including general requirements, message transmission requirements and application-specific requirements

The Application Development task was completed in December 2015. Further refinement to the applications will be conducted as part of the formal testing activities in the project.

2.3 Vehicle Build

During the second and third quarters of 2015, seven of the project Participants built test vehicles for prototyping and testing the selected applications. The test vehicles consisted of six light vehicles and one heavy truck. The test vehicles were integrated with common components that included a DSRC onboard unit, dual GPS receivers and input control components, antennas, vehicle Controller Area Network (CAN) gateway and a wireless router.

Following the hardware integration, all vehicles were tested for full functionality to support the safety applications. At the end of December 2015, all of the test vehicles were complete, which concluded the work in this effort.

2.4 Infrastructure Build

The infrastructure build was also conducted during the third and fourth quarters of 2015. The primary activities in this effort centered around selecting a test facility, identifying required intersection equipment and procuring supplier support needed for the selected test location.

A test track at Fowlerville, Michigan was selected as the test location for the project. The following equipment was built or acquired during this task and temporarily installed at the test track during testing:

- GPS receiver base station for Radio Technical Commission for Maritime Services (RTCM) correction
- Roadside Unit (RSU) and traffic signal controller powered by a portable power generator was used with the RLVW and CSW. A second RSU, also powered by a portable generator, was used with the RSZW. This arrangement provided two independent test setups for use at the track.
- RSU software to provide Signal Phase and Timing (SPaT), intersection MAP and BIM messages to the test vehicles during testing of the three applications.

The infrastructure build was completed in December 2015.

2.5 Testing

During the third quarter of 2015, the initial set of Objective Test Procedures (OTPs) for evaluating the three safety applications was completed. The OTPs were subsequently refined and revised from information obtained during the various tests conducted with the safety applications. Four sets of tests were conducted using the test vehicles and infrastructure equipment built earlier in the project. Maps were generated for each of the test locations as needed using data from surveys or Google Earth.

A base system was initially tested to validate the following:

- Hardware component integration in test vehicles and the operation of the infrastructure equipment (GPS base station, RSU, traffic signal controller, etc.)
- DSRC message communication among the vehicles and the RSU. This included the validation of the over-the-air DSRC message encoding and decoding for MAP, SPaT, RTCM as well as the proposed BIMs for the CSW and RSZW applications.
- Data capture and recording of raw- and encoded-data logs for post-processing and system debugging

Next, two testing sessions were conducted to evaluate application performance and subsequently identify algorithm refinements. The test sessions were conducted on public roads in a real-world driving environment and on a test track for testing violations and validating warnings. The public road phase of testing was conducted on November 5-6, 2015 and featured the follow items:

- For RLVW, a virtual, two-lane intersection was created within the CAMP office complex in Farmington Hills, Michigan. Tests were conducted to validate signal phasing with lane association, map matching and reaching the intersection on the red phase to generate warnings for violation.
- For CSW, tests were conducted on roads near the CAMP office. The roadways selected included radii of curvature of approximately 40, 70 and 480 meters.

- For RSZW, tests were conducted on a road with a permanent lane closure which provided a natural lane closure for test. Tests were conducted for map matching, lane closure, and reduced-speed-zone generation of inform and warning.

On November 17-18, 2015, application performance tests were conducted at the selected test track facility. The RLVW and CSW tests were set up on the dynamics pad and the RSZW test was set up on a 1.4 km-long, four-lane, straight road. Test layouts mimicking real-world scenarios were created. Applications were tested for generating violations and associated warnings. The following test scenarios were conducted during the tests:

- For RLVW, a four-lane intersection was created on the test track using the infrastructure equipment. For generating warnings, the vehicle's approach to the intersection was timed such that the test vehicle reached the intersection either when the signal phase was red, or about to turn red, and a violation occurred. Additional tests were conducted to assess the application algorithm when no violation occurred and a warning should not have been generated. Additionally, "turn prediction" algorithm tests were conducted by performing road-level map matching. All RLVW tests were conducted at an approach speed of 55 mph.

- For CSW, a curvature of 100 m radius was setup mimicking a typical exit ramp of a freeway. To test the algorithm, various road coefficients of friction were induced in the BIM. In addition, reduced visibility was also introduced in the BIM and broadcast from the RSU. The algorithm was tested with various combinations of parameters for generating "Inform," "Warning 1" and "Warning 2" driver messages as appropriate for different test scenarios. All tests were conducted at an approach speed of 70 mph entering the curve.

- For RSZW, a work zone approximately 1 km long was setup on the straight roadway. The work zone layout represented two, right-lane closures and a straight-through lane with reduced speed in the work zone. Tests included a comprehensive assessment of warnings for reduced speed in the work zone with and without the presence of workers and with one and two lanes closed. Tests were also conducted to verify suppression of a warning when a lane change indication is on, indicating that the driver is aware of the lane closure. All tests were conducted at an approach speed of 70 mph.

The data logged during the tests were subsequently analyzed and reviewed for application performance. All three applications worked as intended, although several refinements related to the timing of warnings were identified. Adjustments in the applications were then made based on the test results.

Objective testing for application performance evaluations was conducted on February 9-10, 2016 at the same test track as used in the previous tests. The updated OTPs and refined applications developed during the project were used in these tests. The equipment and test layouts were the same as those used in the November 2015 tests. Applications were tested for generating violations and associated warnings for performance measurement. The following test scenarios were conducted during the tests:

- Tests for RLVW involved ten test scenarios conducted at approach speeds of 35 mph, 55 mph and 70 mph to validate application performance at various speeds
- Six test cases were used to assess CSW with various combinations of parameters for generating Inform, Warning 1 and Warning 2 as appropriate for different test scenarios. As in the prior tests, various road coefficients of friction and low visibility were induced in the BIM for

algorithm performance measurement. Test scenarios were conducted at approach speeds of 35 mph, 45 mph and 55 mph entering the curve.

- For RSZW, five test sets were conducted at approach speeds of 45 mph and 70 mph

Application refinements are planned in the next reporting period to address issues identified during the objective tests. The testing work will also continue into the next reporting period so that updated applications can be re-assessed through objective testing. Additional on-road testing with the applications is also planned for the future.

2.6 Map Support

The Map Support task was initiated in July 2015 with the goal of developing an automated method to generate maps for signalized intersections in the SAE J2735 encoded MAP format. The University of Michigan Transportation Research Institute (UMTRI) was the supplier selected to assist the V2I Consortium in this effort. Seventeen intersections were identified from the Safety Pilot Model Deployment data as candidates for input to the algorithm development and evaluation process. Five of these intersections were subsequently selected for a LiDAR survey to facilitate preparation of reference maps (in MAP format) that will be used in the evaluation of the algorithm's performance. The intersections chosen for the verification step represented various levels of complexity, ranging from simple to very complex.

The data for the 17 selected intersections was then assembled and development of the automated map generation method was initiated. The surveys of the five 'verification' intersections were also initiated. The major activities in this effort included:

- Cleaning of vehicle probe data and trip categorization based on the vehicle path to determine whether or not the vehicle traversed through the intersection
- Development and refinement of an algorithm to estimate vehicle path and lane trajectory for vehicles that traversed through the intersection
- Investigation of the intersections for automatic association of signal phase with generated lanes (for those cases in which the SPaT information was available in addition to the probe data)

The completed algorithm was subsequently applied to data from the five 'verification' intersections selected for assessing algorithm performance. The performance analysis focused on:

- Accuracy of the lane geometry estimated by the algorithm versus the surveyed lane geometry for the intersection (from the reference maps)
- Completed lane combination for multi-lane intersection and stop-bar estimation

A report documenting the algorithm and the analysis of the automated maps generated from the vehicle probe data was prepared. At the time this annual report was prepared, the automated map generation report was in publication review and expected to be released in the near future. Work in this task was completed in March 2016.

3 Road Weather Management Program Connected Vehicle-Infrastructure Research Project

The Road Weather Management Program Connected Vehicle-Infrastructure Research (RWMP-CVIR) Project was initiated on April 20, 2015 and completed in June 2016. The objective of the project was to assess how weather, road condition, and related vehicle data may be collected, transmitted, processed and used in road weather applications and services. This project was a joint effort between the V2I Consortium and the Virginia Tech Transportation Institute (VTTI).

3.1 Coordination of Vehicle System Technical Assistance

This task provides technical assistance to the RWMP regarding vehicle systems related to Connected Vehicle-Infrastructure standards and protocols and the definition of parameters of interest.

3.1.1 Identification of Road Weather Related Variables of Interest

During the year, weather data elements from recent RWMP research were compiled. These included parameters from SAE J2735 Basic Safety Message (BSM) Part 1 & 2 and the Weather Data Frame as defined by FHWA-sponsored research. A set of candidate weather data categories was established and the data elements potentially sourced from OEM vehicle systems were identified. Work on this subtask is complete.

3.1.2 Vehicle Data Element Map

The list of parameters of interest from the prior subtask was matched to specific Data Fields and Data Elements from SAE J2735-2015 to establish a common definition for each variable. Each member of the V2I Consortium selected a representative, high-volume, current-production vehicle and assessed the availability of information needed to populate the desired weather data parameters for their specific vehicle. A preliminary identification of high-priority data elements was made and an assessment of the potential to provide this information across the complete set of 10 vehicles was performed. A mapping of potential BSM Part 1 & 2 weather data parameter availability was reviewed with FHWA in a briefing held September 17, 2015. Work on this subtask is complete.

3.1.3 Candidate Research Vehicle Identification

Work was initiated jointly with FHWA to identify the performance requirements associated with each of the weather data parameters listed in the map established in the previous subtask. This information was used to refine the mapping and identify which vehicles may be candidates for obtaining the desired road weather data in other ongoing FHWA RWMP research projects. A tabulation of those vehicles which may be candidates for obtaining the desired road weather data in other ongoing FHWA RWMP research projects was delivered in November 2015. Work on this subtask is complete.

3.1.4 Support of Ongoing RWMP Projects

Technical support to obtain road weather parameters of interest from the vehicles identified in the prior subtask was initiated. Direct interaction between individual project participants and FHWA contractors was required to manage the proprietary nature of this information.

3.2 Technical Support, Reporting and Pilot Demonstration Proposal

This task reviewed the existing Concept of Operations (ConOps) for the RWMP, assessed the potential for available vehicle data to support the applications identified, and developed a proposal for follow-on research.

3.2.1 RWMP ConOps Review

Review of the RWMP ConOps documents and supporting information was completed. Comments were provided on each of the proposed applications described in the Concept of Operations for Road Weather Connected Vehicle Applications (Final – May 31, 2013 FHWA-JPO-13-047). A review meeting was held September 3, 2015 with FHWA and support staff to discuss the Consortium's perspectives. Work on this subtask is complete.

3.2.2 Preliminary Follow-On Concept Development

A high-level concept was developed for Dynamic Road Surface Mapping (DRSM) to support V2I communications based safety applications. DRSM would crowdsource information from vehicles to significantly improve the spatial and temporal granularity of local road surface condition data for use in vehicle based safety systems while also delivering information to support road weather maintenance operations. The concept was reviewed with FHWA in December 2015 and approval was given to develop technical and cost proposals for a potential follow-on project to explore the concept. Work on this subtask is complete.

3.2.3 Follow-On Technical and Cost Proposal

A proposal for a potential follow-on project to explore DRSM was developed and delivered in March 2016. Work on this subtask is complete.

3.3 Representation at RWMP Events

Under this task, VTTI represented the project team at RWMP stakeholder events and project-related activities to gain exposure to the types of research and discussions taking place between stakeholders and within the industry. The following meetings and events were supported during the year:

- Integrated Mobile Observations (IMO) Program Meeting held August 17, 2015 in Lansing, Michigan
- RWMP Stakeholders Meeting held August 25, 2015 via online meeting
- Integrated Mobile Observations (IMO) Program Meeting held November 17-18, 2015 in Boulder, Colorado
- Transportation Research Board Annual Meeting, Washington, D.C., January 10-14, 2016

- Integrated Mobile Operations (IMO) Stakeholders Meeting, Reno, Nevada, February 10-11, 2016
- RWMP Annual Stakeholder's Meeting, Atlanta, June 18-20, 2016

Work on this task was completed in June 2016.

4 AERIS Eco-Approach and Eco-Departure Planning Project

The Applications for the Environment: Real-Time Information Synthesis (AERIS) Eco-Approach / Departure Planning Project (AERIS-Planning) was initiated on April 28, 2015 and completed in February 2016. The objective of the project was to identify information gaps, define technical and safety needs and propose an evolutionary research plan for developing and evaluating AERIS applications. This project was a joint effort between the V2I Consortium and the Texas Transportation Institute (TTI) in conjunction with the University of California Riverside and the University of Michigan Transportation Research Institute (UMTRI).

4.1 Prepare Research and Development Plan

This task examined the technical feasibility of prototyping Eco-Approach and Eco-Departure (Eco-A/D) applications and established a research plan to develop and evaluate concepts. This work, completed during the reporting period, consisted of four subtasks, summarized below.

4.1.1 Conduct Literature Review

During the reporting period, relevant background documents were collected describing prior and ongoing Eco-A/D research, research topic categories were defined, and key questions were identified for use in conducting a detailed literature review. A total of 167 reports were identified for consideration. Based on a review of abstracts, 63 documents were selected for further review covering six key categories:

1) Eco Concept
2) Vehicle Technical Issues
3) Infrastructure Technical Issues
4) Communications/Standards
5) Human Factors
6) Performance Measures

The selected documents were distributed across the technical team in a dual review format. An additional 15 AERIS documents were subsequently provided by FHWA and were also examined. Results were summarized into an initial set of research questions. A Literature Review meeting was held jointly with the FHWA staff on August 15-16, 2015 to discuss the results and begin formulation of a set of Key Issues and Knowledge Gaps associated with Eco A/D research. Subsequent to the meeting, this list was finalized.

4.1.2 Define / Refine Eco-Signal Application Concept(s), Assumptions and Initial Research Questions

A review of the AERIS Eco-Signal Operations: Operational Concept was conducted and over 200 assumptions identified. These assumptions were combined with the key issues and knowledge gaps (identified earlier) in a spreadsheet and each team member reviewed and prioritized assumptions (high, medium, and low). Team members then provided written comments for their ratings. The results of this analysis provided the assumptions, key issues and next steps that were used to define/refine a concept for Eco A/D research.

4.1.3 Identify Road Map to Address Eco-Signal Research Needs

During the year, team members analyzed the assumptions along with the key issues and knowledge gaps identified and developed a refined operational concept for Eco A/D. The team also developed an evolutionary research plan to explore the potential benefits of deploying an Eco A/D system as well as address the knowledge gaps identified. The research plan is divided into three phases, near-, mid- and long term, covering a ten-year period.

4.1.4 Initial Assessment of Transportation Related Data Sharing

Work on a literature review assessing transportation data sharing was initiated and completed during the year. This analysis summarized Eco A/D relevant data that is currently being shared within and across jurisdictional boundaries, as well as the types of arrangements and best practices in use. A similar effort to document state and Federal policies or laws related to privacy, security, liability and the environmental impact relevant to Eco-A/D applications was also completed.

4.1.5 Prepare Final Report

The team worked to prepare a final report detailing the work accomplished in the project as well as technical and cost proposals for the near-term, research phase identified in the research plan. The Final Report for the project was submitted to FHWA on January 22, 2016. The final briefing was held on January 28, 2016. The final report was in publication review at the time this report was prepared.

5 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 AERIS Planning Project, described in the prior section. The Eco-Approach and Eco-Departure (Eco-A/D) Small Scale Test and Evaluation Project is a joint effort between the V2I Consortium, TTI, and 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 infrastructure owner/operators.

Work in this project was initiated on June 23, 2016, just as the reporting period for this report closed. Consequently, the activities completed to date were largely administrative and start-up in nature. The core technical work will occur during the next reporting period. In lieu of a progress summary, the scope of the work planned for the project is briefly outlined below.

5.1 Simulation Modeling and Performance Analysis

This task will lay the foundation for developing and exercising 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. It will consist of the following subtasks:

- Identify Potential Locations for Implementation
- Characterize Simulation Environment and Traffic Flows

5.2 System Architecture and Algorithm Development

Work in this task will establish a balanced set of vehicle and infrastructure user needs to drive Eco A/D system performance requirements that result in the desired functionality. Work in the System Architecture and Algorithm Development task will consist of defining stakeholder needs.

5.3 Coordination and Outreach

Under this task, the project team will interact with other relevant U.S. DOT programs and projects, including the Connected Vehicle Pooled Fund Study in order to successfully execute the tasks and activities.

6 Cooperative Adaptive Cruise Control Small-Scale Test Project

The Cooperative Adaptive Cruise Control – Small-Scale Test (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 Adaptive Cruise Control (ACC). Only the initial phase of the CACC-SST Project has been awarded. It is scheduled to conclude in February 2017.

6.1 Field Test and Analysis of Empirical Data

The overall goals of this task are to build the simulation environment required for algorithm development and to collect empirical data on ACC operation using test vehicles. This task is organized into the following subtasks.

6.1.1 Scenario Development

The team initiated the definition of test scenarios to be executed on a test track using the test vehicles and the definition of simulation scenarios to be executed during the algorithm development in the simulation environment. Subcategories for the scenarios were defined and used to structure the development. Based on prior work in the previous V2I Consortium's CACC Project, a list of assumptions and definitions on CACC was created to refresh the common understanding of CACC. Together with FHWA, a scenario review meeting was held to discuss the scenario definitions and to collect valuable input and suggestions to improve the scenarios.

The team finalized the definition of both the test scenarios (which will be executed on a test track to characterize ACC performance) and the simulation scenarios (which will be used to support development of CACC). Both scenario types have been categorized and were rated by the technical team based on their importance. The scenario development work was completed in December 2015.

6.1.2 Vehicle Build

Four V2I Consortium participants provided vehicles to support the testing activities to be conducted in this project. A common vehicle architecture was developed for the project. The vehicle architecture will initially support tests with the prototype ACC selected for the project and, later in the project, tests with CACC. Based on this, required hardware components were selected, purchased and integrated into the test vehicles. As part of the hardware selection process, several different radar sensor suppliers were contacted to obtain technical specifications for their radar products. Selection of the radar sensor was subsequently made with inputs and comments from FHWA.

Vehicle integration plans to adapt the hardware and software to the individual test vehicle's on-board systems and communication protocols were also developed. Integration work was then initiated and all vehicles were completed on March 7, 2016. The vehicles will be used during the exploratory tests discussed in the section below.

6.1.3 Exploratory Tests

The exploratory tests are vehicle characterization tests that were conducted using the scenarios defined earlier in the project to obtain data to parameterize the simulation environment for the vehicles and sensors used in the project. During the tests, DSRC, radar, positioning and vehicle dynamics data were collected while the scenarios were executed. The data were then analyzed and the metrics defined during scenario development were evaluated.

Initial work in this task focused on test planning. Working with VTTI, the team further refined the test scenarios and evaluated approaches to evaluate the scenarios. The applicability of the scenarios to the Smart Road, where the tests were conducted, was discussed and parameters for the scenarios, such as vehicle speeds and timings, were defined. Data acquisition systems were installed in the vehicles and practice runs with the test scenarios to familiarize the drivers with the vehicle systems and their behavior were conducted. The logged data was subsequently analyzed and verified to ensure that all parameters of interest could be logged properly.

The test scenarios were then executed and the data was recorded. Multiple review meetings were held as the exploratory tests were conducted to monitor the progress of the tests and review collected data. The tests were completed in June 2016. Data analysis is underway and will continue into the next reporting period.

6.1.4 Simulation Setup

A simulation environment will be used to study different implementation options for CACC in the Algorithm Development, Simulation and Specification work in the project. The objective of this task is to define and implement the simulation environment. The initial work in this task focused on developing a simulation architecture that integrates a microscopic traffic simulator, a communication network simulator and various sensor models. Hardware and software components were purchased and implemented based on the requirements that were defined for the project.

Multiple meetings were held to discuss the implementation approach to the various simulation models and components that comprise the simulation environment for the project. The work in this task is being conducted with UMTRI. Based on the agreements reached during the meetings, UMTRI started implementing the required components through the purchase of required software licenses and computer hardware. UMTRI completed the implementation of the backend architecture that connects all relevant components of the simulation environment such as the VISSIM traffic simulation, the NS-3 network simulator and the Simulink-based sensor models. The environment is currently being debugged and tested using a simple ACC algorithm that will eventually be replaced with the project-developed CACC algorithm. The sensor models were parameterized based on literature data and data collections by UMTRI. As soon as the results from the exploratory tests (discussed in the previous section of the report) are available, the models will be further tuned to the characteristics of the test vehicles.

Implementation of the simulation environment and testing of the software modules will continue into the next reporting period.

6.2 Algorithm Development, Simulation and Specification

In the third quarter of 2015, work on development of the algorithm was initiated by defining an initial software architecture of the CACC system and creating descriptions of the software modules. This architecture was then discussed with the project’s vehicle integrator and UMTRI in multiple technical meetings and further refined. The definition of the software interfaces was initiated based on the data needs of the software modules. The architecture was then refined and restructured and additional required software modules were identified. The architecture was then finalized and the algorithms and requirements for each of the modules were developed and documented.

Three initial software versions were identified which build on top of each other and provide CACC with increased features. This development approach allows for the comparison of different CACC configurations. Revisions to the content of the three software versions may be made in the future as information is obtained during the testing and analysis of the first software version used in the project.

A Hazard Analysis and Risk Assessment (HARA) of CACC was also initiated. Activities in this area were focused on identifying situations in which CACC would need to operate in the following three scenarios:

1. Freeway with operation on a dedicated lane
2. Freeway with operation on a multi-lane environment with unequipped vehicles
3. Rural roads

Following the definition of the situation catalog, the situations were analyzed for their anticipated exposure and the severity of potential system failures, if they occurred in those situations. Work on the HARA will continue into the coming quarters of the project.

6.3 Planning for Phase 2

Planning for Phase 2 was initiated with a meeting between FHWA, V2I Consortium and members of the Connected Vehicle Pooled Fund Study to identify expectations and ideas for a potential next phase of the CACC Project. This meeting was held on May 4, 2016. Based on the discussion during the meeting, a first, high-level concept of Phase 2 was prepared. The concept was presented to FHWA as well as the current project suppliers to seek their input and suggestions for refining the concept. Planning for Phase 2 will continue into the next reporting period and include further interactions with relevant partners to refine the concepts and lead to a technical and cost proposal. The Phase 2 planning work is expected to conclude in October 2016.

7 Work Order 7 - Advanced Messaging Concept Development Project

The objective of the Advanced Messaging Concept Development Project (AMCD) is to evaluate the ability of connected vehicles to generate, and for the 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 includes emulating elements of Dynamic Interrogative Data Collection (DIDC) control, where applicable, in real-world driving conditions for non-safety critical applications.

7.1 Integration Validation Research

The Integration Validation Research Task provides 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.

7.1.1 Test Plan

During the reporting period, work was initiated to review background materials from recent FHWA research relevant to the AMCD Project as well as emerging commercial activities providing similar mobility services. Discussions were held with Noblis regarding the FHWA Basic Safety Message Emulator Project to clarify the applicability of modeling concepts to the AMCD Project and plans for field-testing elements of the Dynamic Interrogatory Data Collection (DIDC) concept.

Based on review of recent FHWA communication research, related commercial activities providing similar mobility services, and interactions with FHWA staff, three primary research objectives were identified which set the framework for the project test plan:

- Characterize dual mode communication (DSRC and cellular)
- Evaluate message control schemes (DIDC and Probe Data Management Logic)
- Message type characterization (BSM, PDM, BMM)

A detailed project test plan was developed around this framework and reviewed with FHWA. Work on this subtask as completed in February 2016.

7.1.2 Prototype Test Preparation

During the reporting period, design work for prototype vehicle and infrastructure system elements was completed. The proposed system architecture was implemented in hardware and software and end-to-end testing on the test bench was successfully completed. The vehicle / infrastructure elements of the system were implemented in preparation for prototype testing on the Smart Road, with two prototype vehicles ready for test as scheduled on June 10, 2016.

7.1.3 Prototype Test Execution

Development testing and refinement of system elements is underway with prototype vehicles operating on the Smart Road in Blacksburg, Virginia. Initial system characterization testing is scheduled to be completed in the next reporting period.

APPENDIX A. List of Acronyms

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
CAMP	Crash Avoidance Metrics Partners LLC
CAN	Controller Area Network
CMC	Consortium Management Committee
ConOps	Concept of Operations
CSW	Curve Speed Warning
CV	Connected Vehicle
CVIR	Connected Vehicle-Infrastructure Research
DIDC	Dynamic Interrogatory Data Capture
DMA	Dynamic Mobility Application
DOT	Department of Transportation
DRSM	Dynamic Road Surface Mapping
DSRC	Dedicated Short-Range Communications
DRSM	Dynamic Road Surface Mapping
DVI	Driver-Vehicle Interface
Eco-A/D	Eco-Approach / Eco-Departure
EVPW	Emergency Vehicle Priority Warning
FHWA	Federal Highway Administration
GPS	Global Positioning System

HARA	Hazard Analysis and Risk Assessment
I2V	Infrastructure-to-Vehicle
IMO	Integrated Mobile Observations
ITS	Intelligent Transportation Systems
LiDAR	Light Detection and Ranging
MAP	SAE J2735 Map Message
NS-3	Network Simulator (Open Source Network Simulation Software)
OEM	Original Equipment Manufacturer
OTPs	Objective Test Procedures
PDM	Probe Data Message
RLVW	Red Light Violation Warning
RSU	Roadside Unit
RSZW	Reduced Speed/Work Zone Warning
RTCM	Radio Technical Commission for Maritime Services
RWMP	Road Weather Management Program
SAE	SAE International
SDO	Standards Development Organizations
SPaT	Signal Phase and Timing
SSGA	Stop Sign Gap Assistance
SST	Small-Scale Test
SWIW	Spot Weather Impact Warning
TTI	Texas Transportation Institute
UMTRI	University of Michigan Transportation Research Institute
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I-SA	Vehicle to Infrastructure Safety Applications (Project)
VCC	Virginia Connected Corridor

VISSIM	Verkehr In Städten – SIMulationsmodell (A Traffic Flow Simulation)
VTTI	Virginia Tech Transportation Institute
Wi-Fi	Wireless Fidelity (Wireless Local Network)

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