Development of Vehicle-to-Infrastructure Applications Program

Fourth Annual Report

www.its.dot.gov/index/htm
Final Report – August 31, 2018
FHWA-JPO-18-704

U.S. Department of Transportation
Federal Highway Administration

Produced by Crash Avoidance Metrics Partners LLC in response to Cooperative Agreement Number DTFH6114H00002

U.S. Department of Transportation
Federal Highway Administration

Notice

Technical Report Documentation Page

1. Report No. **FHWA-JPO-18-704**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development of Vehicle-to-Infrastructure Applications Program Fourth Annual Report		**5. Report Date** August 31, 2018 **6. Performing Organization Code**
7. Author(s) Shulman, Michael and Geisler, Scott		**8. Performing Organization Report No.**
9. Performing Organization Name And Address Crash Avoidance Metrics Partners LLC on behalf of the Vehicle-to-Infrastructure Consortium 27220 Haggerty Road, Suite D-1 Farmington Hills, MI 48331		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH6114H00002
12. Sponsoring Agency Name and Address Intelligent Transportation Systems Joint Program Office U.S. Department of Transportation 1200 New Jersey Ave, SE Washington, DC 20590		**13. Type of Report and Period Covered** Annual Report July 1, 2017 through June 30, 2018 **14. Sponsoring Agency Code**

15. Supplementary Notes

16. Abstract

This report documents the work completed by the Crash Avoidance Metrics Partners LLC (CAMP) Vehicle to Infrastructure (V2I) Consortium during the fourth 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, 2017 through June 30, 2018. 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 and Traffic Optimization for Signalized Corridors. This report provides a summary of key project activities and accomplishments for the period.

17. Key Words	18. Distribution Statement
CAMP, Vehicle-to-Infrastructure (V2I), safety, Cooperative Adaptive Cruise Control (CACC), eco-approach, eco-departure, sustainability, mobility, vehicle control, automation	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

Table of Contents

Executive Summary **1**

1 V2I Program Administration **5**

1.1 Program Administration 6

1.2 Outreach to Infrastructure Owners and Operators 6

1.2.1 Reduced Speed / Work Zone Warning Working Group 6

1.2.2 Signal Phase and Timing / Red Light Violation Warning Verification Working Group 7

1.2.3 Connected Automation Working Group 8

1.2.4 Support for SAE Standards Development 9

2 Vehicle-to-Infrastructure Safety Applications Project **10**

2.1 Coordination with Stakeholders 10

2.2 Adaptation of Reduced Speed Zone/Lane Closure Warning in Texas I-35 Corridor Construction Project 11

2.3 Work Zone Mapping 11

2.4 SPaT Challenge Intersection Verification 12

3 Traffic Optimization for Signalized Corridors Project **14**

3.1 Simulation Modeling and Performance Analysis 14

3.1.1 Algorithm Incorporation 14

3.1.2 Simulate System Operation 15

3.1.3 Estimate Potential Benefits 16

3.2 System Architecture and Algorithm Development 16

3.2.1 System Architecture Development 16

3.2.2 Algorithm Development 16

3.3 System Specifications and Hazard Analysis 17

3.3.1 Hazard Analysis / Risk Assessment 17

3.3.2 Refine Architecture and Algorithm Specifications 17

3.4 TOSCo Phase 2 Planning 18

3.5 Coordination and Outreach 18

3.6 Implement CACC in Test Vehicles 18

3.6.1 CACC Vehicle System Integration 18

3.6.2 CACC Integration Testing 18

APPENDIX A List of Acronyms **20**

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 fourth year of program operation. The period covered by the report is from July 1, 2017 through June 30, 2018. 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 fourth year. Information regarding work previously completed in the V2I Program can be found in the annual reports for the prior years of operations (Shulman and Geisler, 2015, Report No. FHWA-JPO-16-263; Shulman and Geisler, 2016, Report No. FHWA-JPO-16-480; Shulman and Geisler, 2017, in publication).

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

    - Cooperative Adaptive Cruise Control – Small-scale Test (CACC-SST) Project – completed June 2017
- Previously initiated and currently administer the following active projects:
    - V2I Safety Applications (V2I-SA) Project
    - Traffic Optimization for Signalized Corridors (TOSCo) 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 – November 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

- Completed technical assessment of the candidate safety applications, identification of application selection criteria and a selection process for development, field testing and demonstration. Three applications were subsequently selected for development in the project: RLVW, CSW and RSZW/LC.
- Preparation of development plans for the selected applications
- Developed a prototype, over-the-air, Dedicated Short-Range Communications (DSRC) Basic Information Message (BIM) for the CSW and RSZW/LC applications along with a rationale for why this message is needed. This work provided significant contributions to the ongoing development of the Roadside Safety Message (RSM) standard in SAE J2945/4. When completed, the RSM is expected to incorporate the data elements contained in the BIM prototype message developed for this project and the data elements from the infrastructure message called the Basic Infrastructure Message.
- Development of the selected V2I safety applications for test and evaluation
- Integration of the applications into seven test vehicles and preparation of transportable intersection equipment to support testing in the project
- Development of initial test procedures and documentation of the initial test results
- Development of Objective Test Procedures (OTPs), completion of objective testing, and documentation of application performance and analysis results

- Development of a process to automatically generate intersection maps (in SAE J2735 MAP Message format, MAP) using Basic Safety Messages (BSMs) obtained by Roadside Units (RSUs). The process was evaluated using BSM data collected at five intersections used in the USDOT Safety Pilot Model Deployment Program.
- Demonstration of the RLVW, CSW and RSZW/LC applications for V2I stakeholders, including the Connected Vehicle (CV) Pilot sites, Smart City Challenge finalists, the V2I Deployment Coalition, USDOT, and automotive industry representatives. The demonstration was held April 19-22, 2016 at a test track in Michigan.
- Conducted workshops to study the feasibility of adapting the RLVW application to actuated traffic signals. The workshops were designed to gain knowledge of the actuated signal controller technology and to assess the performance impact on current RLVW application and possible resolution.
- Demonstration of the RLVW, CSW, and RSZW/LC applications in Washington, DC on January 24-25, 2017. The demonstration, held in conjunction with the Washington Area New Automobile Dealers Association's (WANADA) connected vehicle technology events, involved participants from the media, automotive industry and governmental units.
- Completed performance evaluation of CSW and RSZW/LC applications on public roads. Test sites, located in Southeast Michigan, included freeway exit and entrance ramp curves and a work zone on I-75 near State Highway M-59 in Auburn Hills.
- A final report on work completed in Tasks 2 through 12 of the project was prepared and was submitted to FHWA on July 27, 2017
- Completed Version 1.2 of the Signal Phase and Timing (SPaT) Challenge Verification Document and delivered the document to the IOO/OEM Forum on November 7, 2017. An interim report on the intersection verification process was also prepared and delivered to FHWA on December 15, 2017.

Traffic Optimization for Signalized Corridors 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 Traffic Optimization for Signalized Corridors (TOSCo) Project is planned in two phases. Phase 1 – Modeling and Analysis will select specific existing traffic corridors as potential TOSCo 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 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 TOSCo 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 IOOs for input
- Identified candidate corridors for TOSCo modeling and implementation. Selected a low-speed corridor in Ann Arbor, Michigan and a high-speed corridor in Conroe, Texas.

- Completed data collection for both candidate low-speed and high-speed environments to facilitate the process of modeling the selected corridors
- Prepared and delivered an interim report on Corridor Selection and Stakeholder Needs
- Modified the project technical proposal to incorporate CACC
- Completed calibrating the simulation environments for the low-speed and high-speed corridors
- Defined the operating scenarios under which the TOSCo function is expected to operate
- Identified the high-level requirements that define the TOSCo system operation. Conducted Review Meeting #3 with FHWA to review the simulation calibration, operating scenarios and system requirements.
- Conducted Review Meeting #4 that focused on TOSCo system architecture and vehicle software algorithm modules
- Developed a detailed approach for assessing algorithm verification and performance impact for the corridor-, vehicle- and infrastructure-levels
- Completed the TOSCo Hazard Analysis / Risk Assessment (HARA) that leveraged previous work accomplished in the V2I Program's CACC Project
- Completed the initial Safety Concept
- Completed integration of CACC functionality in a fleet of four test vehicles
- Completed identification of Functional Safety Requirements
- Completed first round of CACC tests
- Completed definition of the TOSCo System Architecture
- Conducted Review Meeting #4.5 that focused on the two TOSCo system simulation models
- Completed all planned CACC testing and conducted an engineering demonstration on a test track
- Completed draft technical and cost proposals for TOSCo Phase 2 work
- Initiated TOSCo corridor simulation runs
- Conducted Review Meeting #5 that focused on traffic simulation scenarios, method to conduct traffic simulations, exceptions observed in vehicle-level simulation and CACC data analysis

1 V2I Program Administration

This document presents the Fourth 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, 2017 through June 30, 2018. The overall goal of the V2I Program is to develop and test V2I safety, mobility, environmental and automation applications as part of the U.S. Department of Transportation (USDOT) Intelligent Transportation System (ITS) Strategic Plan. The program is administered by Crash Avoidance Metrics Partners LLC (CAMP) under the Program Administration work order. This work order will run throughout the V2I Program. The purpose of the work order is to:

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

The V2I Consortium was formed in 2014 to conduct the projects awarded under the Cooperative Agreement. Current V2I Consortium Participants are Ford, GM, Honda, Hyundai-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 were active during the reporting period. These were:

- V2I Safety Applications (V2I-SA) Project
- Traffic Optimization for Signalized Corridors (TOSCo) Project

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

The projects undertaken through the V2I Program are expected to enhance deployment of driver assistance systems to potentially improve safety and mobility for drivers through improvements in performance made possible by V2I connectivity, while also exploring enhancements to situational awareness possible through improved knowledge of the driving environment. The V2I Consortium considers exploring the potential of V2I communications to improve the performance of vehicle information, warning and control systems to be high-value research. The V2I Consortium believes that cooperative research to explore opportunities to potentially improve safety, mobility, the environment and vehicle control are the highest priority.

In addition to overall program administration activities, the structure of the V2I Program Administration Work Order includes efforts to support initiatives related to the Infrastructure Owners and Operators /

Original Equipment Manufacturers (IOO/OEM) Forum and SAE standards development. As such, three tasks exist in the work order, as follows:

- Program Administration: This task will contain the activities associated with the overall management of the V2I Program and continue the efforts started at Program inception.
- IOO/OEM Forum: This task will focus on the activities associated with participation in the IOO/OEM Forum. The goal of the IOO/OEM Forum is to provide for the exchange of information between OEMs and infrastructure owners and operators that will support the future deployment of V2I and Infrastructure-to-Vehicle (I2V) applications.
- SAE Standards: This task will support the development of SAE standards for V2I applications.

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

1.1 Program Administration

Several deliverables were prepared and submitted to FHWA as part of the work completed 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 30, 2017, October 30, 2017, January 30, 2018 and April 30, 2018.
- Quarterly Progress Briefings, providing a presentation to FHWA of the work performed in the preceding quarter. Quarterly Progress Briefings were completed on August 22, 2017, October 26, 2017, January 22, 2018 and April 19, 2018.
- The V2I Risk Log which consolidates the identified risks for each active project into one report along with the proposed mitigation plans. The consolidated Risk Log was updated quarterly and submitted concurrently with the Quarterly Status Reports.
- The Third Annual Report for the V2I Program (in publication)

Information regarding work previously completed in the V2I Program can be found in the annual reports for the prior years of operations (Shulman and Geisler, 2015, Report No. FHWA-JPO-16-263; Shulman and Geisler, 2016, Report No. FHWA-JPO-16-480; Shulman and Geisler, 2017, in publication).

1.2 Outreach to Infrastructure Owners and Operators

The V2I Consortium continued interactions with the IOO/OEM Forum during the year. In addition to supporting the overall forum activities, the Consortium is also participating directly in three of the forum's working groups. The activities surrounding these groups are presented below.

1.2.1 Reduced Speed / Work Zone Warning Working Group

Monthly Reduced Speed / Work Zone Warning (RSZW) Working Group meetings were held via online meetings throughout the year. Representatives from the V2I Consortium participated in the meetings

and facilitated information exchanges regarding the ongoing V2I projects at CAMP. During the fourth quarter of 2017, the work group extended its work plan to include 12- and 18-month goals.

In addition to the CAMP work in Texas (see Section 2.2) and Michigan (see Section 2.3), the work group reviewed several other RSZW-related projects during the third quarter of 2017, including the Connected Vehicle Information Systems and Network Project in Arizona, Automated Lane Closure Reporting using the Arrow Boards Project in Minnesota and the FHWA Work Zone Data Initiative. The work group continued to monitor these initiatives throughout the reporting period.

In the fourth quarter of 2017, the work group created an outline for a possible model Reduced Speed Zone Warning (RSZW) Concept of Operations document and established a connected work zone initiative tracking matrix to monitor ongoing projects across the country. Preliminary work on the RSZW Concept of Operations (ConOps) was completed during the first half of 2018 and the initial document review by the group was started as the reporting period closed.

The group also tracked the progress of the work zone mapping software toolchain developed under the V2I Safety Applications Project (see Section 2.3). The group plans to promote the toolchain's use across the multiple work zone initiatives and sharing of the lessons learned / suggested refinements to the tool. The software toolchain, consisting of work zone mapping and Reduced Speed Zone Warning (RSZW) message builder applications, was presented to the Cooperative Automated Transportation Coalition working group on June 13, 2018.

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 led by the V2I-SA Project Principal Investigator (PI), who coordinated the exchange of information regarding CAMP's V2I projects. The group met monthly during the reporting period.

In preparation for receiving a revised SPaT Challenge Verification Document from the V2I Consortium, the working group discussed and defined a process for sharing the document with stakeholders and for updating the document in the future. The working group decided to distribute the verification document through the National Operations Center of Excellence (NOCoE) website and to update the verification document twice a year, as warranted based on user feedback.

The V2I Safety Applications team revised the initial SPaT Challenge Verification Document, incorporating the lessons learned from conducting the verification process at two intersections in Southeastern Michigan. See Section 2.4 later in this report for more information about this work. The Safety Applications Project Team also researched and incorporated into the verification document material on satellite-based positioning error correction methodologies and possible approaches to positioning corrections at signalized intersections. Additionally, the V2I-SA Project, working in conjunction with the SPaT/RLVW Verification Working Group, developed a questionnaire-based template to capture "lessons learned" by the IOOs and local agencies during SPaT Challenge equipment installations.

The revised SPaT Challenge Verification Document and the lessons learned questionnaire were provided by CAMP to the IOO/OEM Forum in November 2017. The documents are now posted on the NOCoE's website (https://transportationops.org/spatchallenge). In the last two years, the number of operating Roadside Units (RSUs) has grown to an estimated 500 units across 35 locations in 25 states. At the end of the reporting period, approximately 80 individuals had downloaded the SPaT

Challenge Verification Document and feedback had been received from several individuals. CAMP presented the SPaT Challenge Verification Document and work zone mapping for connected work zone at the IOO/OEM Forum meeting held on December 7-8, 2017.

The SPaT/RLVW Verification Working Group also held six SPaT webinars during the reporting period that covered several topics, including design considerations, intersection MAP creation tools, deployment and validation. The webinars were intended for a larger audience than just the forum members. Two webinars were conducted in the fourth quarter of 2017 while the remaining four webinars were conducted during the first half of 2018. The SPaT Challenge Verification Process was presented on June 12, 2018 during the final webinar in this series.

The CAMP V2I-SA Project is engaged with a supplier to develop a handheld visualization tool to assist with the verification of received intersection SPaT and MAP messages against the actual signal light status and associated roadway lanes. The visualizer overlays the information on an aerial view of the intersection being verified. Earlier discussions at the IOO/OEM Forum identified the need for such a tool to assist road operators in verifying equipment installations at signalized intersections.

Development of a draft version of a SPaT Infrastructure System Model ConOps document by the work group was completed during the second quarter 2018. The initial version of the draft was provided to the work group for review and comment.

Additionally, the V2I Consortium continued to participate in the SPaT Challenge resource team.

1.2.3 Connected Automation Working Group

The TOSCo Project PI met with the IOO/OEM Forum Connected Automation Working Group during their scheduled meetings throughout the year to provide an exchange of information between the TOSCo Project and the working group members. Notable exchanges of information made during the year included the following:

- Presentation of the TOSCo vehicle operating use cases was provided and a preliminary discussion of requirements for the Basic Information Message (BIM) regarding broadcast of queue length information was held during working group meetings in August and September 2017

- Presentation of the TOSCo Project status and the infrastructure operating use cases to the working group at the November and December 2017 meetings. A discussion of requirements for the BIM regarding broadcast of queue length information, initiated during earlier working group meetings, was also held. The PI also presented the TOSCo Project status at the IOO/OEM Forum meeting on December 7, 2017.

- Presentation of the TOSCo Project status, infrastructure requirements, simulation algorithm development and continued discussions of requirements for the Roadside Safety Message (RSM) regarding broadcast of queue length information were provided during working group meetings in January, February and March 2018

- Presentation of the TOSCo Project status and the infrastructure requirements, simulation algorithm development during working group meetings in April, May and June 2018. Discussions of the requirements for the RSM regarding broadcast of queue length information continued in these meetings. The TOSCo Project Team also presented a suggestion to incorporate TOSCo functionality in appropriate SPaT Challenge corridors, which received a

favorable response from forum participants, although much work would need to be accomplished within the TOSCo Project before this suggestion could proceed.

- In May 2018, the TOSCo Project provided an overview of TOSCo corridors for distribution within the IOO/OEM Forum

1.2.4 Support for SAE Standards Development

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

- J2945/0 - This standard will establish systems engineering principles for the J2945 suite of standards. It will provide guidance on how to read and interpret the J2945/x family of documents to assist standards-based deployments and procurement processes. Use of channel 172 for message communications for two V2I safety applications was established and passed the committee ballot. Currently, action on this standard resides with the SAE Motor Vehicle Council.

- J2945/3 - Requirements and user needs for V2I Weather Applications

- J2945/4 – DSRC Messages for Traveler Information and Basic Information Delivery (i.e., the Traveler Information Message, BIM). The DSRC TC has agreed to rename the BIM (Basic Information Message / Basic Infrastructure Message) to RSM. This standard will serve to re-work and extend the existing SAE J2735 message elements to include additional travel and roadway information from the infrastructure to enhance safety awareness and promote the exchange and transfer of such message types between vehicles and the infrastructure. The TC has continued to review and revise drafts of the standard to incorporate updates for the RSZW and CSW applications and to include new use cases related to static signage, situational and dynamic information, and incidents. The V2I SA Project, in coordination with the Connected Vehicle Pooled Fund Study (CV PFS), American Association of State Highway and Transportation Officials (AASHTO) and the Southwest Research Institute (SwRI), has provided the document sponsor with revised Abstract Syntax Notation One (ASN.1) definitions for the additional data elements for the J2735 data dictionary to support RSZW, CSW and other V2I safety applications (use cases) that use the RSM. The most recent material submissions by the V2I-SA Project and CV PFS stakeholders were in February and May 2018.

- J2945/10 - Recommended Practices for MAP/SPaT Message Development.

2 Vehicle-to-Infrastructure Safety Applications Project

The V2I-SA Project started on September 15, 2014 and is scheduled to run through November 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 fourth year of program operations, outreach efforts in the V2I-SA Project included interactions with the Infrastructure Owners and Operators / Original Equipment Manufacturers (IOO/OEM) Forum, the New York City (NYC) Connected Vehicle (CV) Pilot site and the Michigan Department of Transportation (MDOT).

On September 25, 2017, representatives from several CAMP projects, including the V2I-SA and TOSCo Projects, attended a meeting in New York City regarding the NYC CV Pilot. The meeting was organized by FHWA and hosted by the NYC Department of Transportation. The primary purpose of the meeting was an information exchange between CAMP and NYC. During the meeting, the CV Pilot applications, pilot vehicles, infrastructure plans, technical issues and challenges encountered in vehicle positioning, message standards, DSRC channel band plan, and the Security Credential Management System Proof of Concept (SCMS PoC) were discussed along with potential solutions to the issues and questions raised.

The V2I-SA Project also continued to hold monthly update meetings with the MDOT to coordinate activities underway in Work Zone Mapping Task and in the SPaT Challenge Intersection Verification Task. See Sections 2.3 and 2.4 below.

In addition, a portable tool to visualize received SPaT/MAP messages was evaluated in June 2018 at several MDOT intersections in the Detroit area. This work was conducted as part of a development effort underway with an infrastructure equipment supplier. The tool evaluated presents the SPaT and MAP information from messages sent by an RSU on the display of a tablet computer, permitting easy comparison with the actual signal status and lane configurations at the intersection. The need for such a tool was identified during work previously completed in the SPaT Challenge Verification Task and in discussions at the IOO/OEM Forum. Information acquired during the evaluations was provided to the supplier to aid in refinement of the tool.

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

In this task, the RSZW/LC application, developed earlier in the V2I-SA Project, will be evaluated through pilot field testing on selected sections of the I-35 corridor under construction in Texas. Work in this task was initiated in July 2017 and early efforts focused on providing the Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI) with information about the functionality of the developed RSZW/LC application and the application requirements. The discussion of the requirements included required data elements, reference vehicle requirements, RSU requirements and mapping requirements. The initial draft of a guideline document for TxDOT installation and use of the RSZW application was also completed during the third quarter of 2018 as was the work plan, schedule and milestones for the cooperative work in the task. A regular cadence of meetings was identified to support the exchange of information needed to complete this task, address questions and issues that might arise during task execution and review task progress.

Discussions with TxDOT and TTI regarding the RSZW/LC application and application requirements have been on going throughout the task. During the fourth quarter of 2017, the draft guideline document for installation/use of the RSZW application was revised cooperatively with the TxDOT/TTI team and expanded to include work zone mapping techniques. It is anticipated that the guideline document produced this task could provide future assistance to other IOOs tasked with deploying connected work zones. The TTI/TxDOT team also presented a status update to FHWA on December 19, 2017 as a scheduled milestone.

On March 26-28, 2018, TxDOT and TTI hosted a 2-1/2-day connected work zone workshop in Austin, Texas. The workshop was attended by representatives from the TxDOT, TTI, CAMP, FHWA, Volpe Center and SwRI that are involved in the Connected Work Zone Project and this task. Technical and project updates were discussed during the workshop. The workshop also included a field visit to the work zone on I-35 near Temple, Texas that will be used in this task. During the drive to the site, approximately 8 km of construction zone were mapped using the software from the toolchain developed the Work Zone Mapping Task (see next section).

Since the workshop, discussions with the TxDOT and TTI team have centered on procuring equipment for test vehicles and infrastructure equipment, RSUs for application testing, placement of RSUs in the construction zone and the interface with the Texas Lonestar backend server for lane closures. Discussions also included work zone mapping using the V2I-SA Project's mapping toolchain.

2.3 Work Zone Mapping

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

- Vehicle Path Data Acquisition System – collects vehicle path data using an instrumented test vehicle
- Work Zone Map Builder – processes previously collected vehicle path data and generates a work zone map required for the RSZW/LC BIM

- Work Zone Map Visualizer – generates the work zone map in human-readable form (i.e., in eXtensible Markup Language, or XML, format) and overlays it on a Google satellite-view map for visual verification
- CV Message Builder and Verifier - creates an encoded map message, based on Unaligned Packed Encoding Rules (UPER), from the XML map format and decodes the map message back to XML for verification. This encoded message is in an RSU-independent format.

The initial development of the applications that collect vehicle path data, process the path date into a BIM map and generate the work zone map in XML format was completed during the third quarter of 2017. Successful tests of the RSZW/LC application were subsequently conducted using the XML format work zone maps that were prepared using the three software tools. Tests were conducted on a 5.5-mile-long work zone on I-75 in Southeastern Michigan using the RSZW/LC application in the project's previously-built test vehicles. To facilitate testing, an RSU that accepts work zone maps in the XML format was used.

Development of the application that creates the UPER-encoded message was also initiated during the third quarter of 2017. The initial development of this application extended through the end of 2017.

Following the initial development of the four applications, refinements and enhancements were made to accommodate more complex work zones, the presence of workers and simplify the operation of the applications. These efforts are described below.

During the Fourth Quarter of 2017, new and simplified data elements/frames to represent complex work zone maps that support multiple lane closures and multiple lanes open as well as zones where workers are present were developed. New data elements were also defined for an ASN.1 structure for the data dictionary in the SAE J2735 standard. Previously developed software components were further refined and enhanced to support new data elements and more complex work zones for mapping. The application to create the UPER-encoded message was further revised and tested to support the additional data elements. Testing in actual work zones was conducted to assess the revisions to the tools.

In the first half of 2018, several improvements were made to the toolchain applications to support additional flexibility in representing work zone configurations and to simplify the map. Enhancements to the ASN.1 source code were also made to support the AASHTO / SwRI-developed use cases for static signage, situational and dynamic information and incidents.

The CV Message Builder application was revised and tested to support the data elements for additional use cases. The message builder algorithm was also enhanced to address a large complex work zone that required generation of a message larger than the length allowed by the SAE standards and, consequently, could not be transmitted as a single message by the RSU. The enhanced message builder algorithm properly segments the message into multiple pieces for transmission. Further refinement and enhancement of all software applications will continue, as needed, in the next reporting period and will be tested in live work zones. The work in this task is expected to be completed in October 2018.

2.4 SPaT Challenge Intersection Verification

The purpose of this task was to refine the intersection verification process described in the SPaT Challenge Verification Document, originally prepared in March 2017 by the V2I Consortium. This document was prepared to assist with connected intersection deployments made as part of the

IOO/OEM Forum SPaT Challenge. In this task, verification of signalized intersections in Southeast Michigan were conducted to confirm that the over-the-air messages sent by the intersection RSU, that is the SPaT and MAP messages, will support the Red Light Violation Warning application. This work was conducted in cooperation with MDOT.

Verification of two intersections equipped with RSUs transmitting SPaT/MAP messages was conducted during the third quarter of 2017. The sites were located on Mound Road at the intersections of 12 Mile and 13 Mile Roads in Warren, Michigan, near the GM Tech Center. The intersections were initially equipped with the 2015 version of the SPaT/MAP standard and subsequently updated by the MDOT to the 2016 version of the standard. Verifications were conducted for both versions of the SAE standard.

In addition, the subject of error sources in satellite-based position-correction methodologies were investigated and potential approaches for positioning corrections at signalized intersections equipped with the RLVW application were identified. A summary of this work was prepared and delivered to FHWA by presentation.

Based on work completed in this task, the SPaT Challenge Verification Document was revised to include new information obtained during the intersection verification work and to incorporate the summary of positioning correction options available to IOOs. The updated SPaT Challenge Verification Document was provided to the IOO/OEM Forum on November 7, 2017. The document is available through the NOCoE's website.

A project interim report, based on the revised SPaT Challenge Verification Document, was completed and submitted to FHWA on December 15, 2017. This work is now complete.

3 Traffic Optimization for Signalized Corridors Project

This project addresses near-term research needs on the Eco-Signal application development roadmap established by the previously completed CAMP Applications for the Environment: Real-Time Information Synthesis (AERIS) Planning Project. The TOSCo Project[1] is a joint effort between the V2I Consortium, TTI, the University of Michigan Transportation Research Institute (UMTRI), and the University of California Riverside (UCR). TOSCo uses wireless data communications from RSUs to connected vehicles to optimize mobility, fuel economy and emissions while traveling along urban corridors of equipped signalized intersections. The project is planned in two phases. Phase 1 – Modeling and Analysis will select specific existing traffic corridors as potential TOSCo 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 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 TOSCo Phase 1. The project was initiated on June 23, 2016.

3.1 Simulation Modeling and Performance Analysis

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

3.1.1 Algorithm Incorporation

Work on this subtask was initiated during the third quarter of 2017. During this quarter, the Project Team developed a detailed approach for assessing algorithm verification and performance impact for the corridor-, vehicle- and infrastructure-levels. Verification questions, experimental plans, analysis setup and performance measures for each level were defined.

During the fourth quarter of 2017, the Project Team worked to integrate logic to represent system behavior into VISSIM (Verkehr In Städten – SIMulationsmodell), including Adaptive Cruise Control (ACC), CACC and TOSCo vehicle behavior and initial infrastructure algorithms for queue estimation, Green Window determination, and BIM generation. The Project Team also added the Advanced Signal Control (ASC) Software Controller to the simulation environment to produce SPaT data for the simulation model.

The Project Team implemented the TOSCo vehicle and infrastructure algorithms into both the vehicle-level and traffic-level simulations during the first quarter of 2018. Much of the vehicle-level algorithm was implemented during April and May 2018. A vehicle-level simulation verification plan and metrics

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

were also developed. At the traffic-level, the team developed a SPaT Message Distributor to receive SPaT data from a virtual controller in the simulation environment that distributes SPaT data to the infrastructure algorithm with intersection ID. The Team also integrated new components into the infrastructure simulation. The new components included adding loop detector data and coordinated actuated control into the virtual traffic controller. This task was completed at the end of May 2018.

3.1.2 Simulate System Operation

Work on this subtask began on November 1, 2017. The objective of this subtask is to exercise the traffic-level simulation models by varying the parameters identified in the System Architecture and Algorithm Development Task (Section 3.2) to observe the models' ability to calculate queue lengths and generate speed profiles which directly affect the performance of the TOSCo function. Performance of the TOSCo function in optimizing mobility, fuel economy and emissions reduction based on changes in input parameters will be observed. The Project Team will then use these observations to determine if the algorithms developed require modification.

The Project Team began performing initial infrastructure simulations and analyses for queue length estimation and BIM generation runs on intersections along State Highway (SH) 105 in Conroe, Texas and Plymouth Road in Ann Arbor, Michigan. The Project Team also initiated traffic simulation runs to test and verify speed profile generation and representative TOSCo behavior.

During the first quarter of 2018, the Project Team began verification of software by first designing both functional as well as evaluation-level test scenarios and performing functional level tests. The Project Team verified TOSCo software by using the following seven functional test scenarios:

- String maintains constant speed to pass through intersection
- String speeds up to pass through intersection
- String slows down to pass through intersection
- String stops at the intersection
- String speeds up to pass through intersection in the presence of a queue
- String slows down to pass through intersection in the presence of a queue
- String stops at the intersection in the presence of a queue

The project team identified a vehicle-level verification plan and measures that proved valuable in identifying functional exceptions in TOSCo algorithm performance during vehicle-level simulations. Single-intersection simulations were also performed.

The Project Team created a validation plan for traffic-level TOSCo behavior to ensure that simplified TOSCo behavior is representative of true TOSCo vehicle-level behavior. The executed plan revealed a need for refinement of traffic-level vehicle behavior which was accomplished. Traffic-level assessments of entire corridors for both the Texas and Michigan corridors are currently underway. TTI configured all intersections on the SH 105 corridor in Texas to support TOSCo operations with each intersection operating in coordinated-actuated mode as they exist on the corridor.

It is anticipated that fine-tuning of the vehicle behavior in the simulation will continue into the next reporting period to provide the desired speed profile generation and mode selection logic in the vehicle-level simulation and to achieve consistency in vehicle behaviors between TTI and UMTRI traffic-level models.

3.1.3 Estimate Potential Benefits

Work on this subtask began on November 1, 2017. The Project Team first developed an experimental plan and integrated the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) model into the VISSIM models. The performance metrics were identified and finalized, and the experimental plan was refined.

The Project Team conducted preliminary performance analyses for the SH 105 and Plymouth Rd. corridors at single intersections (Plymouth Rd./Huron Parkway in Michigan and SH 105/LaSalle Ave. in Texas) and performed simulations to understand the differences between preliminary results for SH 105 and Plymouth Rd. intersections. The Project Team has begun traffic-level assessments for the Texas and Michigan corridors. Work in this subtask will continue into the next reporting period as data from the Simulate System Operation Subtask becomes available for analysis.

3.2 System Architecture and Algorithm Development

The objective of this task is to establish the TOSCo system architecture and develop the vehicle and infrastructure algorithms needed to support TOSCo functionality. The architecture and algorithms will then be incorporated into the simulation environment discussed above. Previously in this task, a list of stakeholder needs was defined, test scenarios to be used in the simulation environment were developed and system objectives and the functional requirements for the vehicle and infrastructure components of a TOSCo system was completed.

3.2.1 System Architecture Development

This system architecture supports the traffic corridor alternatives identified earlier in the project and the algorithms developed in the Algorithm Development Subtask discussed in the next section. The system architecture defines how the vehicle and infrastructure components exchange the information needed to allow strings of TOSCo-equipped vehicles to traverse a corridor of equipped intersections.

In August and September 2017, the system objectives were revised to address seven key functional elements: coordinated stop, coordinated travel and coordinated launch for the lead vehicle of a string, and coordinated stop, coordinated travel, coordinated launch and a new creep mode for members of a string. The system architecture and vehicle algorithm modules were presented to FHWA during Review Meeting #4 on September 21, 2017. This subtask is complete.

3.2.2 Algorithm Development

The objective of this subtask is to develop the algorithms needed to implement the TOSCo function(s). The Project Team will evaluate multiple TOSCo implementation options that may be available within the system architecture developed in previous subtasks using the simulation environments developed under the Simulation Modeling and Performance Analysis Task (Section 3.1). Work on this subtask started on August 1, 2017.

The Project Team completed TOSCo software version 1 at the end of 2017. This software version included the Coordinated Stop, Speed Control and Optimized Follow operating modes. The remaining operating modes of Coordinated Launch and Creep will be the subject of software version 2 because these more complicated modes require additional development time. Software version 1 also incorporated a vehicle localization algorithm based on VISSIM data, logic for vehicles to determine impending green, an infrastructure algorithm to calculate the Green Window (in two versions, one

developed by UMTRI and one developed by TTI). Software version 1 addresses a single intersection with fixed signal control.

TOSCo software version 2 was completed during the first half of 2018. This version covers the Coordinated Launch and Creep operating modes. The Project Team also added improvements to the Mode Selection module and made improvements to the speed profile for Coordinated Launch and began modelling the queue length estimation algorithm for software version 2 in mixed traffic with both BSM and detector data.

While conducting simulations of TOSCo vehicle software version 2, the Project Team identified the need to revisit specific vehicle algorithm specifications. At the traffic-level, the Project Team completed the queue length estimation algorithm for software version 2 in mixed traffic conditions with lower penetration of connected vehicles and worked with the City of Conroe, Texas to enable queue detection on existing radars at the intersection of SH 105 and Old Highway 105W. The team also collected queue detector data and video at this intersection to refine infrastructure algorithm and calibrate error rates.

Work in this task will continue into the next reporting period to address software exceptions discovered during analysis of preliminary simulations.

3.3 System Specifications and Hazard Analysis

The objectives for this task are to create and refine a TOSCo system specification, documenting the TOSCo functionality developed and evaluated. A 'safety concept' will also be developed for the proposed TOSCo system that addresses both vehicle and infrastructure components. The overall TOSCo 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 completed work to develop the Hazard Analysis / Risk Assessment (HARA). Four hazards were identified and defined. The hazards identified are incorrect excessive acceleration, incorrect insufficient deceleration, incorrect excessive deceleration and incorrect insufficient acceleration. Insufficient acceleration was subsequently determined to not represent an Automotive Safety Integrity Level rated (ASIL-rated) hazard. The Project Team also completed the TOSCo fault tree analysis and the safety concept that includes 45 functional safety requirements in the final version. This subtask is now complete.

3.3.2 Refine Architecture and Algorithm Specifications

Work on this subtask began on December 1, 2017. The objective of this subtask is to refine the TOSCo system architecture and algorithm specifications based on the performance observed in simulation. The findings from the HARA will be incorporated into the specifications to ensure that the desired functionality is achieved at minimum estimated risk and that the risk factors and design choices made and the role of the system components, including the driver and environment, are well understood. Initial simulation results are needed prior to refining the architecture and algorithm specification. The work in this subtask will continue into the next reporting period to coincide with completion of the work in the Algorithm Development Subtask, as discussed above.

3.4 TOSCo Phase 2 Planning

The objective of this task is to build upon the results obtained in Phase 1 to develop technical and cost proposals for follow-on work that will focus on evaluation of TOSCo functionality along the actual urban arterials that were selected for simulation modeling. The Project Team initiated an update to the framework originally provided in the Phase 1 Statement of Work. Draft technical and cost proposals for the TOSCo Phase 2 Project were prepared and delivered to the FHWA on March 29, 2018.

3.5 Coordination and Outreach

Under this task the TOSCo 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:

- Participation by the TOSCo PI in the IOO/OEM Forum Connected Automation Working Group throughout the reporting period. The activities associated with this outreach effort were previously described in Section 1.2.3 as part of the summary for the IOO/OEM Forum activities.
- The Project Team contacted the City of Conroe, Texas to provide an update on the TOSCo Project and obtained access to the traffic controller cabinets on the corridor to inventory equipment needs.
- Presentation of a TOSCo Project update to the Department of Energy Advanced Research Projects Agency - Energy (ARPA-E) Next-Generation Energy Technologies for Connected and Automated On-road Vehicles Program (NEXTCAR Program) in April 2018
- Prepared a TOSCo Project overview for FHWA presentation at the ITS America Annual Meeting in June 2018
- Provided a TOSCo Project overview for presentation by FHWA at the Automated Vehicles Symposium scheduled for July 2018

3.6 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 CAMP CACC-SST Project Phase 1. The existing ACC-equipped vehicles, also from the CACC-SST Project, will be used as the test vehicles in this effort. Work in this task will verify correct operation of the CACC vehicle system.

3.6.1 CACC Vehicle System Integration

The Project Team completed work to integrate and debug the CACC algorithms. Four prototype vehicles are ready for CACC testing in a controlled environment. This subtask was completed in September 2017.

3.6.2 CACC Integration Testing

Work on this subtask began on October 1, 2017. The objective of this subtask is to conduct integration testing of the CACC prototype test vehicles from the previous subtask on a test track. The Project

Team worked with its partners and contractors to develop a detailed test and verification plan and conducted an initial set of tests in December 2017. Planned testing activities included performing necessary parameter tuning and adjustments and verifying intended CACC vehicle system operation.

The Project Team worked with its partners and contractors to complete all scheduled testing during the first quarter of 2018. The testing subtask culminated in an engineering demonstration on March 9, 2018 of the CACC function at a proving ground in Fowlerville, Michigan. Analysis of the CACC data collected during testing was subsequently completed and the results were presented at Review Meeting #5 held June 7, 2018. Efforts are now underway to prepare a chapter for the TOSCo Phase 1 Final Report that details the findings and observations from this effort.

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
ARPA-E	Advanced Research Projects Agency - Energy
ASC	Advanced Signal Control
ASIL	Automotive Safety Integrity Level
ASN.1	Abstract Syntax Notation One
BIM	Basic Information 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 LLC
CMC	Consortium Management Committee
ConOps	Concept of Operations
CSW	Curve Speed Warning
CV	Connected Vehicle
CVIR	Connected Vehicle-Infrastructure Research
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
EVPW	Emergency Vehicle Priority Warning
FHWA	Federal Highway Administration
HARA	Hazard Analysis / Risk Assessment
I2V	Infrastructure-to-Vehicle

Acronym	Definition
ID	Identification Number
IOOs	Infrastructure Owners and Operators
ITS	Intelligent Transportation Systems
MAP	SAE J2735 Map Message
MDOT	Michigan Department of Transportation
MOVES	MOtor Vehicle Emission Simulator
NEXTCAR	Next-Generation Energy Technologies for Connected and Automated On-road Vehicles (Program)
NOCoE	National Operations Center of Excellence
NYC	New York City
OEMs	Original Equipment Manufacturers
OTPs	Objective Test Procedures
PFS	Pooled Fund Study
PI	Principal Investigator
PoC	Proof-of-Concept
RLVW	Red Light Violation Warning
RSE	Roadside Equipment
RSM	Roadside Safety Message
RSU	Roadside Unit
RSZW	Reduced Speed/Work Zone Warning
RSZW/LC	Reduced Speed Zone Warning / Lane Closure
RWMP	Road Weather Management Program
SAE	SAE International
SCMS	Security Certificate Management System
SH	State Highway
SPaT	Signal Phase and Timing

Acronym	Definition
SSGA	Stop Sign Gap Assistance
SWIW	Spot Weather Impact Warning
SwRI	Southwest Research Institute
TC	Technical Committee
TOSCo	Traffic Optimization for Signalized Corridors (Project)
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UMTRI	University of Michigan Transportation Research Institute
UPER	Unaligned Packed Encoding Rules
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2I/I2V	Vehicle-to-Infrastructure / Infrastructure-to-Vehicle
V2I-SA	Vehicle-to-Infrastructure Safety Applications (Project)
VISSIM	Verkehr In Städten – SIMulationsmodell (from German, a Traffic Flow Simulation Package)
XML	eXtensible Markup Language

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

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

FHWA-JPO-18-704

U.S. Department of Transportation