Sharing Data between Mobile Devices, Connected Vehicles and Infrastructure

Task 5: Prototype Proof of Concept Field Demonstration Experimental / Field Demonstration Site Plan - Final

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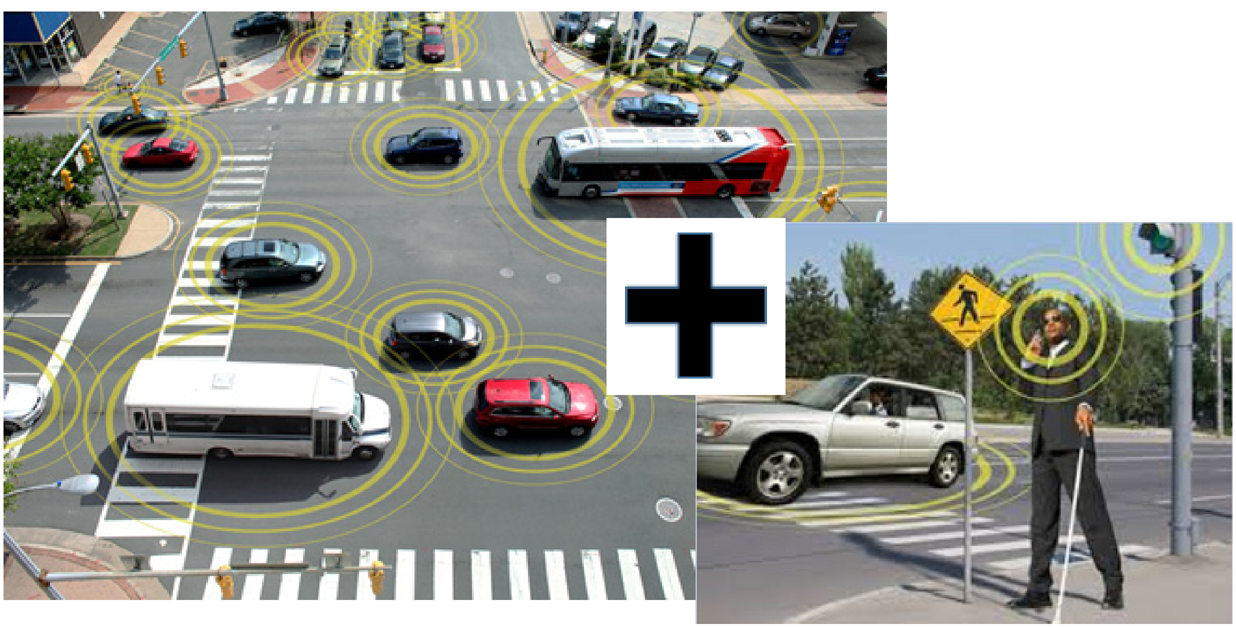

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16. Abstract
This Prototype Proof of Concept Field Demonstration contains the Demonstration Site Plan and the Demonstration Experimental Plan for the project "Sharing Data Between Mobile Devices, Connected Vehicles and Infrastructure" to be performed at Turner Fairbank Highway Research Center in McLean, Virginia. This project investigates the foundational issues associated with including mobile devices into the connected vehicle environment.

This Prototype Proof of Concept Field Demonstration contains the Site Plan and the Experimental Plan for the project "Sharing Data Between Mobile Devices, Connected Vehicles and Infrastructure" to be performed at Turner Fairbank Highway Research Center in McLean, Virginia. This project investigates the foundational issues associated with including mobile devices into the connected vehicle environment

The Prototype Proof of Concept Field Demonstration Site Plan describes the recruitment and identification of Test Participants (e.g., drivers); and their roles and responsibilities (e.g., installation, training, data collection, technical support, project management, test oversight), the identification of training requirements for Test Participants and a description of how the training will take place, the identification of required components and plan for conducting all stages of the Prototype Proof of Concept Field Demonstration to include installation and removal of all in-vehicle devices (and identification of who is responsible); installation check out tests prior to the demonstration (to ensure required components are functional); and plans for a dry run before the field demonstration. The Site Plan layout is shown to reflect the location of demonstration area at TFHRC, including driver routes, areas of operation of the prototype, and any infrastructure equipment. This includes schedule of events describes the planning, preparation, and demonstration activities.

This Prototype Proof of Concept Field Demonstration Experimental Plan demonstrates that the system meets the objectives of the project. The Experimental Plan identifies the demonstration hypotheses, testing protocols, and data elements to be collected. Experiments described in this document are intended to test and demonstrate concepts of mobile device message coordination presented in the Concept of Operations document. Various components of the system are presented including message types, communications methods, and the function of applications within the system. The experiment setup and initial configuration are presented. Each experiment is comprised of a list of procedures. Each procedure has a list of expected outcomes and verification methods.

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Revision	Date	Change Description	Affected Sections/Pages
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1	08/04/2016	Draft Release	All Chapters
2	09/08/2016	Final Release addressing comments received	All Chapters
3	10/06/2016	Final Release (review version)	Addressing final U.S. DOT comments

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Chapter 1 Scope

The United States Department of Transportation (U.S. DOT) has conducted significant research on the use, benefits, and operational issues associated with using dedicated short-range communications (DSRC) and cellular devices in both vehicular and infrastructure-based communications. Specifically, the benefits are intended to improve the safety, mobility and environmental impact on our surface transportation system. When the concept of connected vehicle environment first emerged, DSRC was conceived as an enabler for the mobility-impaired and other travelers with unique needs. However, the unprecedented adoption of smartphones and similar devices in the general population has necessitated a renewed analysis of its role in the broader connected vehicle environment. To date, less research has been conducted on implementation pathways, policy and institutional impediments, as well as the feasibility of deployment of low-latency wireless communications on mobile devices in concert with the current cellular and Wi-Fi communications protocols. In particular, key questions and issues exist related to the expected impact that personal mobile devices (e.g., tablets, smartphones, etc.), that are also equipped with DSRC technology, will have on channel utilization and error-rates in the connected vehicle environment. If saturation is reached, it will likely degrade the anticipated benefits of connected vehicle safety applications by requiring more processing of radio messages than can be performed in low-latency required situations. It is with these considerations that this research is being initiated, the objectives of which are:

1. Examine the feasibility and benefits of utilizing non-DSRC communication mechanisms for the transmission of probe and safety messages.
2. Develop and test modifications to the existing probe and safety messages to make them applicable for mobile devices.
3. Create and demonstrate potential methods for coordinating messages and communications related to safety and mobility between mobile devices, vehicles, and infrastructure.

Importantly, the scope of this document and the system described herein is limited to an experimental system that will be used to design, test, and demonstrate new communication messages and message types as well as explore the effectiveness and potential mechanisms for coordinating these messages across multiple mobile devices, vehicles, and roadside infrastructure. This is intended as a research project and therefore does not seek to identify, define, summarize, or propose a system suitable for immediate wide-scale deployment.

1.1 Document Identification

This document is the draft for the Prototype Proof of Concept Field Demonstration deliverable of Sharing Data between Mobile Devices, Connected Vehicles and Infrastructure project, which is being conducted by Battelle Memorial Institute for the Federal Highway Administration (FHWA) under Contract Number DTFH61-12-D-00046. This document addresses both the Site Plan and the Experimental Plan for the project.

1.2 Document Overview

This document primarily focuses on the Prototype Proof of Concept Field Demonstration Site Plan and the Prototype Proof of Concept Field Demonstration Experimental Plan. The remainder of this document consists of the following sections and content:

- Chapter 2 (Applicable Documents) describes any external documentation referenced throughout this document.
- Chapter 3 (Field Demonstration Objectives) describes the purpose and the high-level desired outcomes of the Prototype Proof of Concept Field Demonstration.
- Chapter 4 (Prototype System Description) provides an overview of the various components of the system.
- Chapter 5 (Site Plan) describes the physical characteristics of the site and identifies test participants, training, and test schedule
- Chapter 6 (Experimental Plan) develops hypotheses, performance measures, and targets along with analysis techniques and risks for assessing the hypotheses.
- Appendix A contains the Acronyms and Abbreviations
- Appendix B contains the Terms and Definitions
- Appendix C provides the method for notifying drivers and pedestrians

The Prototype System Description outlines the system functionality and describes the hardware functionality, software functionality, and the various messages types in the EPS. There are many connected vehicle applications that can be supported through the use of mobile devices and used to demonstrate the objectives of this project. A number of applications were presented in the ConOps and System Requirements documents, but only a subset of the applications and their associated requirements need to be tested to demonstrate that the objectives of the project are met. The various requirements tables in the System Requirements document contain a column to indicate which requirements are included in the EPS.

This deliverable describes the plans, logistics, and schedule for conducting the Sharing Data between Mobile Devices, Connected Vehicles and Infrastructure projects Prototype Proof of Concept Field Demonstration. The Site Plan identifies all the demonstration elements associated with the Prototype Proof of Concept Field Demonstration. It describes the roles and responsibilities of all test setup, logistics, and schedule for the demonstration. The test setup will contain information regarding roles and responsibilities. The Prototype Proof of Concept Field Demonstration will demonstrate the arrangement of travel between travelers and travel providers, coordination between travelers, mode transition detection, the coordinated transmission of PSMs, and communications between mobile devices and a Roadside Unit (RSU) via DSRC. The Prototype Proof of Concept Field Demonstration will include multiple mobile devices coordinating with a connected light duty taxi vehicle and a connected transit bus. The Site Plan provides:

- An overview of the Prototype Proof of Concept Field Demonstration and test scenarios,
- Setup and Layout for the Test at the U.S. DOT Turner Fairbank Highway Research Center
- Equipment and Applications Used for the Test

- Prototype Proof of Concept Field Demonstration participants and training
- Prototype Proof of Concept Field Demonstration preparation and checkout
- Prototype Proof of Concept Field Demonstration schedule

The Prototype Proof of Concept Field Demonstration Site Plan complements the Experimental Plan, which describes the hypotheses, testing protocols, and data elements to be collected.

The purpose of the Field Demonstration Experimental Plan is to describe the field demonstration experiments for demonstrating the operation of mobile devices in a connected vehicle environment and the operation of message coordination applications/algorithms. The Experimental Plan describes the testing procedures, the plan for data capture, and the evaluation plan which will be used to verify that the system is working as intended. This Experimental Plan demonstrates the coordinated transmission of BSMs via DSRC and identifies the demonstration hypotheses, testing protocols, and data elements to be collected. The Prototype Proof of Concept Field Demonstration will assess whether or not the system is able to confirm hypotheses that correspond to project objectives. The Prototype Proof of Concept Field Demonstration will include multiple mobile devices coordinating with a light duty passenger-transporting vehicle (taxi), and a transit bus. The connected taxi and transit bus are capable of transmitting messages that can be received by mobile devices and receiving messages generated by the mobile devices via DSRC and the cellular network, to be discussed later. Prior to the arrival of the taxi or transit bus, travelers can coordinate travel to reduce the number of safety and mobility messages broadcast over DSRC. When the taxi or transit bus arrives at a pickup location, travelers carrying mobile devices will enter the vehicle, and the travelers in the vehicle will cease broadcasting safety and mobility messages. The purpose of reducing the number of messages sent via DSRC will limit the likelihood of degradation of DSRC communications. The taxi or transit bus will discharge passengers at which point the passengers (now pedestrians) will again broadcast mobility and safety messages. Message reception by additional DSRC-capable mobile and/or roadside devices will be logged as a part of the demonstrations that focus on coordinated and uncoordinated travel.

The Experimental Plan describes:

- Hypotheses to be tested during the demonstration
- Benefits of coordinated message generation and transmission
- Performance measures and targets
- Experimental data consistent with the nature of the hypotheses to be tested (e.g., “with” and “without” coordination) that need to be collected to determine if the hypotheses have been demonstrated are valid, and the process by which the data will be collected both by devices in the test as well as other technology deployed to receive and log transmitted messages
- Processes for verifying data quality and for cleaning data, and minimum thresholds for data quality
- Types of analyses that will be conducted on the data

1.3 Intended Audience

The primary audience for this document is U.S. DOT staff and other identified stakeholders who are leading or are interested in understanding the impact of safety and mobility messages from mobile devices within the envisioned connected vehicle environment where DSRC, Cellular, Wi-Fi, Bluetooth and other communication protocols are utilized by both vehicles and mobile devices. Additional audiences include the system developers, engineers, and any others who will assist in the development of a fully deployed Connected Vehicle environment.

Chapter 2 Referenced Documents

This research is sponsored by the U.S. Department of Transportation as part of on-going research related to the connected vehicle program. As such, there are a number of reports, presentations, and documents on the various aspects of the connected vehicle program that can be found at http://www.its.dot.gov/research_documents.htm. The findings, schematics, results, and conclusions in these documents were routinely consulted and are incorporated in this document. Specific references in the following sections pertain only to documents and works that are not included in this public document repository.

2.1 Non-Government Publications

Society of Automotive Engineers (SAE)

J2735:2016	Object Dedicated Short Range Communications (DSRC) Message Set Dictionary – published
J2945/1:2016	On-Board System Requirements for V2V Safety Communications– published
J2945.9 - draft	Performance Requirements for Safety Communications to Vulnerable Road Users

National Transportation Communications for ITS Protocol (NTCIP)

1201:2005 V02.27	Global Object Definitions
1202v03 – draft	Object Definitions for Actuated Traffic Signal Controllers (ASC) – version 03 will include data elements and messages that are coordinated with the SAE J2735 standard, but also data elements for addressing pedestrian and bicycle needs at signalized intersections.

Battelle Memorial Institute

FHWA-JPO-15-TBD	Coordination of Mobile Devices: Technology and Standards Scan (June 19, 2015)
FHWA-JPO-16-422	Task 3: Concept of Operations Document for Coordination of Mobile Devices for Connected Vehicle Applications (3rd Revised Report from July 13, 2016)
FHWA-JPO-16-423	Task 3: System Requirements Specifications for Coordination of Mobile Devices for Connected Vehicle Applications (Final from July 14, 2016)

2.2 Works Cited

- Connected Vehicle Reference Implementation Architecture (CVRIA) and Systems Engineering Tool for Intelligent Transportation (SET-IT), available at http://www.iteris.com/cvria/html/about/about.html
- "2015-2019 ITS Strategic Research Plan," available at http://www.its.dot.gov/strategicplan/
- http://www.its.dot.gov/safety_pilot/safety_pilot_progress.htm
- http://www.its.dot.gov/dma/index.htm
- "ITS Research Archive", available at http://www.its.dot.gov/research_archive.htm
- "Intelligent Transportation Systems National Architecture," available at http://www.iteris.com/itsarch/html/user/userserv.htm
- U.S Department of Transportation, Joint Program Office, ITS Standards Program, http://www.its.dot.gov/press/2013/connected_vehicle_Architectureworkshop.htm
- "Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Concept of Operations," Battelle under Contract to FHWA: DTFH61-06-D-0007, 2012.
- http://www.its.dot.gov/factsheets/certification_factsheet.htm
- "Conduct Scan of Technology, Application Standards, and Stakeholder Engagement," Draft Final Report, Battelle, 2015, Contract Number: DTFH61-12-D-00046

2.3 Works Consulted

- "Connected Vehicle Certification Program," available at http://www.its.dot.gov/factsheets/certification_factsheet.htm
- "Conduct Scan of Technology, Application Standards, and Stakeholder Engagement," Draft Final Report, Battelle, 2015, Contract Number: DTFH61-12-D-00046
- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary [SAE J2735] Using Systems Engineering Methods, SAE J3067, 2014-08-26
- Dedicated Short Range Communications (DSRC) Message Set Dictionary™, SAE J2735, 2009-11-19
- IEEE 802.11™: Wireless LANs Standards
- U.S. DOT, About ITS Standards. http://www.standards.its.dot.gov/LearnAboutStandards/NationalITSArchitecture)
- Message Sets for Advanced Traveler Information System (ATIS), SAE 2354, 1999-11-27
- US DOT Vehicle to Pedestrian (V2P) Technologies Database http://www.its.dot.gov/press/2015/V2P_TechScanDatabase.xlsx

- Proposed extended BSM Messages to be used in the Analysis, Preliminary Draft, January 3, 2015, as prepared by ARINC Incorporated for US DOT under Contract DTFH61-10-D-00015, Task Order 1403.
- Technical Report 1: Data Capture and Management Program Standards-related Requirements Collected, as prepared by ConSysTec, et. al, under contract to Cambridge Systematics for US DOT, March 30, 2015
- DCM Database, as prepared by ConSysTec in support of US DOT Data Capture and Management Program, March 30, 2015
- Development of the Long-Term Connected Vehicle Standards Framework, Final Draft, Version 2.1, November 13, 2014, as prepared by SAE International, et. al, for US DOT.

R.E.S.C.U.M.E. Reports

- FHWA-JPO-14-TBD R.E.S.C.U.M.E. Prototype Acceptance Test Summary
- FHWA-JPO-14-TBD INC-ZONE and RESP-STG Final Prototype Demonstration Report
- FHWA-JPO-14-TBD Technical Report on Prototype Development and Field Testing of R.E.S.C.U.M.E. Applications

V2I Performance Requirements

- FHWA-JPO-15-248 through FHWA-JPO-15-254 Vehicle-to-Infrastructure (V2I) Safety Applications Performance Requirements, Vols 1 to 7,

2.4 Order of Precedence

In the event of a conflict between the text of this document and the references cited herein, the inconsistencies should be brought to the attention of the project manager. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

Chapter 3 Prototype Proof of Concept Field Demonstration Objectives

The main objective in verifying the viability of mobile devices in the connected vehicle space is to conduct a demonstration of the prototype system in a controlled environment to verify that the project objectives, listed below, are being satisfied.

- Demonstrate the potential for message coordination among mobile devices and transmission of messages.
- Evaluate the potential benefit and potential issues associated with the transmission of probe and safety messages from hand held mobile devices via alternative communications media.
- Develop and test modifications to probe and safety messages for mobile devices that complement existing and emerging standards for messages from vehicles, and coordinate those proposed modifications with mobility application developers and standards development organizations.
- Create and demonstrate potential methods for coordinating safety and mobility messaging linking mobile devices carried by pedestrians into light and transit vehicles that may be capable of generating one or more related safety and mobility messages.
- Evaluate the ability of RSU equipment for supporting applications on mobile devices and traffic management activities.

Battelle has recommended conducting this demonstration at the Turner Fairbank Highway Research Center (TFHRC) in McLean, VA. The site provides a controlled environment from which experiments can be conducted. The Battelle Team will work with Turner-Fairbank staff to set up the EPS on-site at the TFHRC. Monitoring equipment and logs on all devices used during the demonstration will be used to verify that the EPS is working as intended in the controlled environment and to assess the benefits of travel coordination, traveler safety, and traveler mobility.

The first objective of the Prototype Proof of Concept Field Demonstration is to evaluate the potential benefit and potential issues associated with the transmission of probe and safety messages from hand-held mobile devices via alternative communications media. Of primary concern is the number of messages sent via DSRC communication media. This will involve the monitoring of messages originating from DSRC-capable devices to quantify the number of messages being sent at a time in the experimental system.

The second objective of the Prototype Proof of Concept Field Demonstration is to demonstrate that methods that have been developed to determine when a mobile device can stop broadcasting messages via DSRC are working properly. Coordination of travel between mobile device users as well as in-vehicle detection are expected to be precursors to the ceasing of the broadcasting of safety messages.

The third objective of the Prototype Proof of Concept Field Demonstration is to demonstrate support of safety and mobility needs of mobile device users as they pertain to the scope of the EPS. Applications included in the system are expected to allow mobile device users to request travel on a taxi or transit bus and provide various levels of advance notice to pedestrians and vehicles when interaction between the two entities is possible.

The final objective of the Prototype Proof of Concept Field Demonstration is to demonstrate the ability of the RSU to communicate with mobile devices. The RSU will broadcast SPaT and MAP messages via DSRC at regular intervals, which can be received by mobile device. Applications supported by these messages are not developed as part of this project. The RSU will receive and store various messages received via DSRC that are broadcast from mobile devices. This demonstrates that DSRC messages can be used to support traffic management center activities, though processing and analysis of this data for TMC-related purposes is not in the scope of this project.

Results from the Prototype Proof of Concept Field Demonstration are expected to provide guidance on the potential design and scope of a Prototype Field Demonstration to follow. It is intended to demonstrate that the controlled environment system can function in an operating environment and can provide a basis for planning a more comprehensive field deployment and test of the technology.

Chapter 4 Prototype System Description

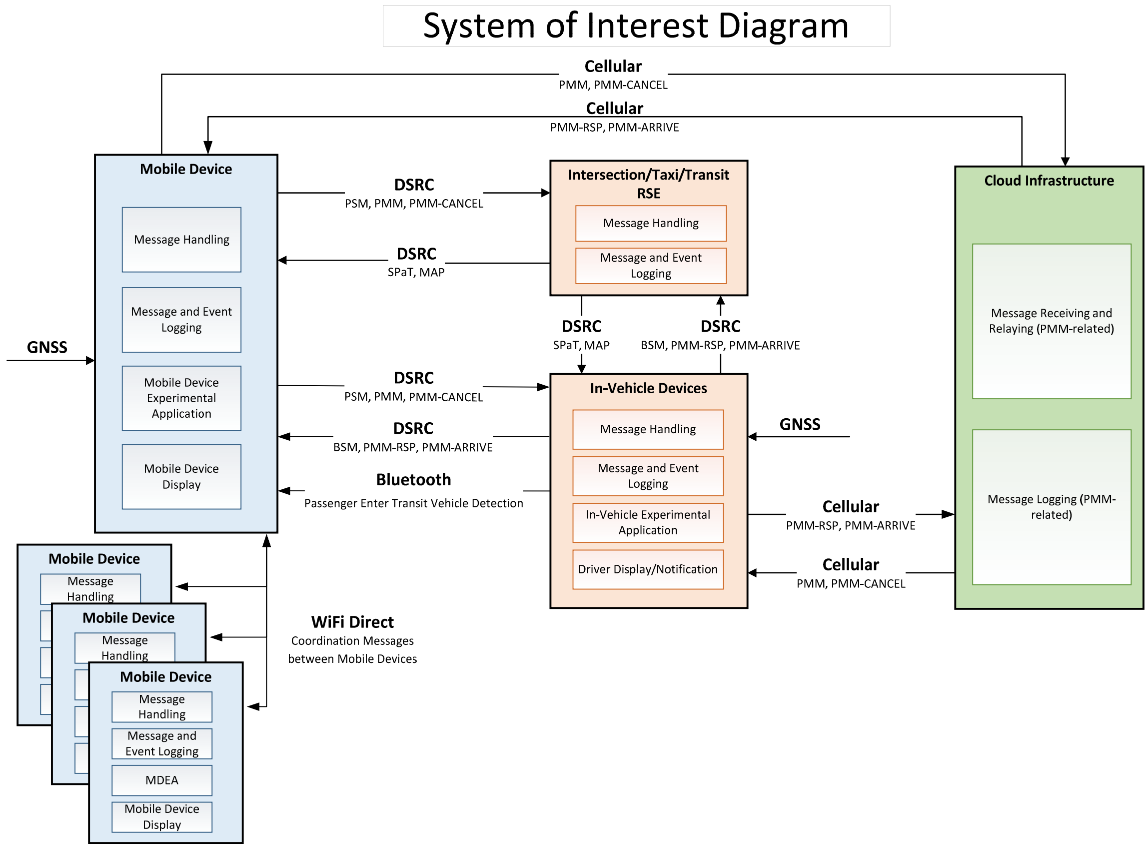
This section provides descriptions of the system components and the system configuration that will be used to coordinate travel between various users of the system. The sections in this chapter provide details regarding the prototype system, mobile devices and in-vehicle devices, message types, and a description of the applications that will be running on mobile devices and on in-vehicle systems.

4.1 Prototype System

The system of interest diagram in Figure shows the elements within the system, capabilities of each element, and the various methods of communication and messages that are transmitted between elements in the system. Mobile devices are capable of message handling, message and event logging, contain the MDEA, and have a display, which is used to interact with the traveler when necessary. Mobile devices are capable of broadcasting PSMs and PMMs to in-vehicle devices via DSRC. Mobile devices can also use DSRC to broadcast PMMs to roadside equipment, and the cellular network to send PMMs to cloud infrastructure. Lastly, Wi-Fi Direct is used to coordinate, maintain, and dissolve travel groups comprised of a group of mobile devices.

In-vehicle devices are capable of many of the same functions as mobile devices, but the application is catered toward the taxi/transit provider through the VEA. In-vehicle devices broadcast BSMs via DSRC. PMMs can be sent to mobile devices via DSRC or cellular. In-vehicle devices also emit Bluetooth signals to allow mobile devices to detect when they are inside of the vehicle.

The cloud infrastructure essentially acts as a relay between mobile devices and in-vehicle devices, and is essential when mobile devices and in-vehicle devices are not within DSRC communication range. The cloud infrastructure relays PMMs between mobile devices and in-vehicle devices via cellular.



Source: Battelle

Figure 4-1. EPS System of Interest Diagram

Coordination is used in more than one context throughout the Prototype Proof of Concept Field Demonstration system. In general, coordination is defined as the successful communication between two or more devices that results in the provision of mobility services. The first type of coordination in this system occurs between vehicles and a mobile device user. In this context, the mobile device user and the vehicle exchange mobility messages (described later in this section) to coordinate, allowing the vehicle to provide mobility services to the mobile device user. The second type of coordination occurs between multiple mobile device users during ad-hoc travel group formation. In this context, a mobile device user exchanges ad-hoc travel coordination messages (described later in this section) to coordinate, thereby providing mobility to the joining member. Both coordination contexts are used throughout the remainder of this test plan.

4.2 System Hardware Components

Hardware used in the EPS is represented by the large blue, orange, and green elements in Figure 4-1. There are four types of hardware included in the EPS: Mobile Devices, In-Vehicle Devices, Intersection RSE, and Cloud Infrastructure. Each type of hardware is described in the following subsections.

4.2.1 Mobile and In-Vehicle Devices

The ideal platform for the mobile device would be a modern smartphone that also includes the capabilities of sending and receiving SAE J2735 compatible messages over DSRC. Unfortunately, at the time of this design, such a device is not commercially available to this project. Therefore, the mobile device component is broken down into an Android based smartphone and a portable DSRC radio. For the purposes of the experiments performed in this investigation, a mobile device will be simulated through pairing of an Android Smartphone (Google Nexus 5X) as the computational platform, and a DSRC Radio (Arada Locomate ME "Backpack"). Similarly, the purposes of the experiments performed in this investigation In-Vehicle devices will be simulated through pairing of an Android Tablet or Smartphone with an Arada Locomate Mini 2. These components are described below.

4..2.1.1 Android Smartphone

The computational platform and user interface used for the simulated Mobile Devices will be the Google Nexus 5X smartphone running the Android operating system, shown in Figure 4-2. The smartphone interfaces with the DSRC radio module in the mobile device via Bluetooth connections. The smartphone supports the implementation of the Mobile Device Experimental Application which provides the following functions:

- Analysis of location data and generation of PSM messages for broadcast via DSRC
- Analysis of GPS and sensor data to determine travel mode of user
- Analysis and processing of incoming messages and generation of safety advisories and alerts where warranted
- Generation of travel request messages for communication via DSRC and/or cellular and processing of replies
- Cellular interface to send and receive cellular based PMM messages and replies
- Bluetooth interface with the DSRC radio module to send and receive DSRC based PSM and PMM messages and replies
- Wi-Fi-Direct interface for forming and coordinating ad-hoc travel with a local traveler group
- Graphical user interface to display safety advisories and alerts
- Graphical user interface to obtain travel request information from users and display replies
- Message and event logger

Source: Battelle

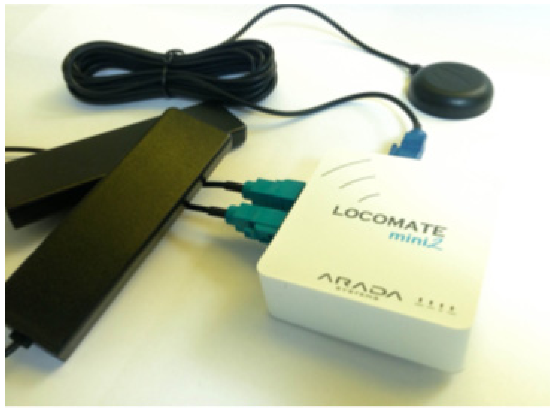
Figure 4-2. Google Nexus 5X Smartphone used as Vehicle Computational Platform and User Interface DSRC Radio Module

The DSRC Radio Module is a small portable unit that provides DSRC radio communication for the Mobile Device. The smartphone receives messages from the DSRC radio and the cellular network (via the Bluetooth paired mobile device). For this test, the Project Team is using the battery powered LocoMate™ ME on-board unit (OBU) with integrated GPS and DSRC antenna, also known as the “Backpack,” shown in Figure 4-3 for the Mobile Device DSRC radio. The backpack form factor is used with the Google Nexus 5X smartphone as an integrated “Mobile Device.”

Source: Arada/Battelle

Figure 4-3. Arada Locomate ME Battery Powered DSRC Communication Hardware, also known as the “Backpack”

For in-vehicle systems, the Team is using Arada System's LocoMate Mini 2 OBU, which allows the use of external GPS and DSRC antennas, as shown in Figure 4-4. Both units use the same radios, circuitry, and software, but are enclosed in a different external case.



Source: Arada/Battelle

Figure 4-4. Arada Locomate "Mini2" DSRC Radio with External GPS and DSRC Antenna

4.2.2 Roadside Unit (RSU)

The Roadside Equipment used for testing and demonstration is the Arada Locomate™ RSU, which is responsible for receiving messages transmitted via DSRC and sending them to a local display and storage device. The local storage device represents a TMC (or other management entity), and the ability to store received messages simulates the ability of sending messages to a TMC that could use the data for traffic management purposes. Messages received by the RSU will be sent to a display unit for experimental monitoring and testing purposes. Battelle will conduct a dry run of the test and ensure all equipment is performing as intended the day before the test.

4.2.3 Connected Vehicles

- Simulated Taxi for PMM Coordination Experiments – A four-door light-duty vehicle capable of carrying up to three (3) "travelers" and one (1) "observer"1. Travelers are able to enter and exit the vehicle using front or rear passenger doors. The vehicle will be equipped with a temporarily-installed Connected Vehicle OBU, which can be rapidly switched on and off to simulate equipped or unequipped vehicle.
- Oncoming Vehicle for PSM Pedestrian Safety Experiments - A light-duty vehicle used to demonstrate pedestrian warning applications for pedestrians in safe/unsafe zones.
- Simulated Transit Bus for PMM Coordination Experiments – A shuttle bus or equivalent vehicle capable of carrying more than nine (9) "travelers" and "observers" combined. Travelers enter and exit the vehicle through a doorway on the front passenger's side of the bus. The vehicle will be equipped with a temporarily-installed Connected Vehicle OBU which can be rapidly switched on and off to simulate equipped or unequipped vehicle.

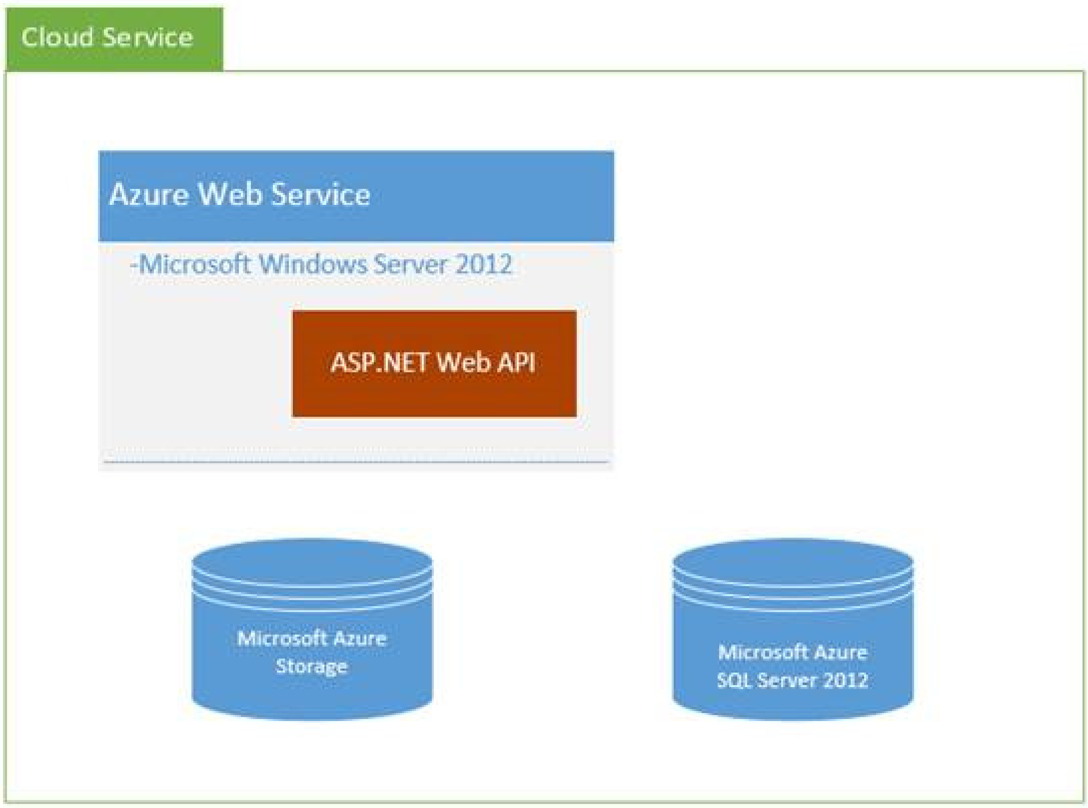
[1] Travelers are individuals who enter and exit the vehicles as passengers. Observers confirm the results and outcomes for each step of the experiment. Travelers and Observers are further defined in Section 05.1 Test Participants Identification

4.2.4 Database and Cloud Service

The Cloud Service will be a Microsoft Azure Cloud Service comprised of the following components:

- Azure SQL Database
- Azure Web Service
- Azure Storage

The computing platform in the Azure Cloud Service will be selected as shown in Figure 4-5.



Source: Battelle

Figure 4-5. Cloud Service Computing Platforms

4.3 System Software Components (Applications)

As can be seen from Figure 4-5, software will be developed for Mobile devices (Mobile Device Experimental Application), in-vehicle devices (Vehicle Experimental Application), and the RSU (RSU Experimental Application). Each software that is developed will be used to support the subset of system requirements specified in the System Requirements documents. All software that is developed will be made available on the Open Source Application Development Portal (OSADP) once the field demonstrations are complete, the field demonstrations report has been finalized, and any modifications to the application code (based on field demonstration results) have been made. The three applications used in the EPS are described in the subsections below.

4.3.1 Mobile Device Experimental Application (MDEA)

The Mobile Device Experimental Application (MDEA) is an application installed on smartphones that allows a traveler to enter an origin and destination and coordinate travel with transit/taxi providers. It is capable of receiving input from the traveler through mobile device interface. The MDEA is capable of coordinating travel with other travelers, and broadcasting PMMs via DSRC or the cellular network. The MDEA also controls the various coordination messages used to form, maintain, and disband travel groups via Wi-Fi Direct. The MDEA is capable of receiving and interpreting BSMs coming from vehicles to alert the pedestrian of potential collisions with a vehicle. Lastly, the MDEA is capable of receiving SPaT and MAP messages originating from an Intersection RSE.

The capabilities of the MDEA, described above, are used to support two applications that comprise the MDEA: pedestrian safety monitoring and travel coordination.

4.3.1.1 Pedestrian Safety Monitoring

This application uses information received in BSMs to compute the vehicle's future path along with information about the pedestrian's predicted path to determine the potential for collision with a DSRC-equipped vehicle. Note that various methods for determining the future location of a mobile device or a vehicle are currently being considered. If a collision is possible, an advisory, alert, or warning will be issued to the pedestrian, depending on the vehicle's speed and/or distance to the path intersection.

4.3.1.2 Travel Coordination

This application allows pedestrians to coordinate travel with a taxi, transit bus, or other vehicle. On a mobile device, the application allows a user to specify travel details and travel requirements and send this information in a PMM. The application receives PMM-RSP to indicate the trip has been accepted and receives PMM-ARRIVE messages which contain arrival information for the vehicle. If multiple PMM-RSPs are received or if a traveler decides to cancel a trip, then the mobile device can send a PMM-CANCEL. The application is also used in the formation of travel groups. It allows Coordination Request messages to be sent to attempt to coordination with travelers within Wi-Fi Direct range. If the trip details of two travelers matches, a Coordination Confirmation is sent. If a group member wishes to disband from the group, the application sends a Coordination cancel message. Finally, upon entering the vehicle, a disband message is sent to all group members.

4.3.2 Vehicle Experimental Application (VEA)

The Vehicle Experimental Application (VEA) is the vehicle-based counterpart to the MDEA. In this experiment, the VEA is installed in taxi and transit vehicles and is capable of receiving input from the taxi or transit bus driver through the OBD. The VEA is capable of receiving travel requests via DSRC or cellular, sending out BSMs via DSRC, and providing travel acceptance and location updates back to the group leader via DSRC or cellular. Also, the VEA is capable of receiving and interpreting other BSMs (not tested in this experiment) and PSMs (to alert or warn drivers in the vicinity of pedestrians).

The capabilities of the VEA, described above, are used to support two applications that comprise the VEA: pedestrian safety monitoring and travel coordination.

4.3.2.1 Pedestrian Safety Monitoring

This application uses information received in PSMs to compute the pedestrian's future path along with information about the vehicle's predicted path to determine the potential for collision with a mobile-device-carrying pedestrian. Note that various methods for determining the future location of a mobile device or a vehicle are currently being considered. If a collision is possible, an advisory, alert, or warning will be issued to the driver, depending on the vehicle's speed and/or distance to the path intersection.

4.3.2.2 Travel Coordination

This application allows pedestrians to coordinate travel with a taxi, transit bus, or other vehicle. In a vehicle, the application receives a PMM, and presents the information in the PMM to the Driver. The driver is given to option to accept or reject a PMM. If a PMM is rejected, nothing happens, but if the PMM is accepted, a PMM-RSP is sent back to the mobile device via the same communications method that the PMM was received. Also, PMM-ARRIVE messages are sent which contain arrival information for the vehicle. The application also receives PMM-CANCEL messages.

4.3.3 RSU Experimental Application

This application will be installed on the RSE, and is capable of storing all messages that are received via DSRC. The messages that are received are not used to support any other activities or processes associated with the RSU Experimental Application. The RSU Experimental Application is also capable of sending SPaT and MAP messages via DSRC. The messages are expected to contain simulated information – not necessarily read from a signal controller.

4.4 Message Types

Messages, the media over which they are communicated, and the entities they are communicated from/to are shown using black arrows in Figure 4-1. The messages used in the EPS can be categorized into safety, mobility, coordination, and RSU message types. Safety Messages (BSM and PSM) are used to communicate vehicle and vulnerable road user (VRU) location information and generally support safety applications. Mobility messages (PMM, PMM-RSP, PMM-ARRIVE, and PMM-CANCEL) are sent between mobile devices and vehicles so that mobile device users are able to arrange travel with a transportation provider, such as a transit vehicle or a taxi. Coordination messages (Coordination Request, Coordination Confirmation, and Coordination Cancel) are sent between mobile devices to allow mobile device users that have similar itineraries to form, maintain, and dissolve travel groups on an unplanned, ad-hoc basis. Finally, RSU messages include SPaT and

MAP messages that are broadcast from an Intersection RSE. These messages do not support any applications in the EPS, but could support future safety and mobility applications. Messages included in each of these message type categories are detailed in the subsections below.

4.4.1 Safety Messages

The BSM is defined by the standard J2735:2016, and is used to broadcast time, location, velocity (speed), and heading information. It is inherent that BSMs are broadcast from vehicles. These messages can be received by devices that have DSRC antennas (could be another vehicle or a mobile device equipped with DSRC communications technology), and are nominally broadcast via DSRC at a rate of 10 Hz – less frequent transmission rates are possible when congestion controls are implemented (SAE J2945-1).

The PSM is the pedestrian adaptation of the BSM, and is transmitted by mobile devices carried by pedestrians (not in a vehicle). The PSM will contain information such as position, speed, and heading, among other information. Because PSMs are only broadcast when a traveler is a pedestrian, it is inherent that traveler sending the PSM is a vulnerable road user. Connected vehicle applications can utilize PSM data to alert vehicles of a pedestrian in the vicinity of a street or a pedestrian in the street or crosswalk. Like the BSM, the PSM is intended to only be conveyed via DSRC at a nominal rate of 10 Hz to support the safety needs of mobile device-carrying pedestrians.

Part of this experiment will assess the coordination of PSMs when multiple travelers are waiting at the same location (e.g., a taxi stop or a bus stop). PSM coordination involves a designated group leader sending out PSMs for the group. All members except the group leader cease broadcasting PSMs. Thus, the PSM includes a data element that indicates the size of the group waiting at the given location.

4.4.2 Mobility Messages

Mobility-based applications, such as the coordination of travel groups, are enabled by the PMM, PMM-RSP, PMM-ARRIVE, and PMM-CANCEL messages.

4.4.2.1 Personal Mobility Message (PMM)

PMMs are sent between travel group leaders and a transit or taxi service to plan travel. They are sent at regular intervals – first via DSRC, and if no response is received, then by cellular – until a taxi or transit agency sends a travel confirmation back to the traveler initiating the request. If another traveler coordinates travel with the group leader (through coordination messages, Section 4.4.3), the group leader can send an updated PMM to the taxi or transit service provider to determine if the travel group can be accommodated.

Information contained in a PMM include, a traveler's destination and their requirements for travel such as schedule constraints, and mobility needs.

4.4.2.2 Personal Mobility Message Response (PMM-RSP)

The taxi or transit service may reply to the PMM (or updated PMM) sent from a group leader's mobile device using a PMM-RSP. A PMM-RSP is only sent from a vehicle back to the traveler who sent the original PSM using the communications media that the original PMM was received on (DSRC or cellular). Receipt of the PMM-RSP by the travel group leader is acknowledgement that the vehicle that sent the message can accommodate the trip request, as specified in the PMM.

Information included in a PMM-RSP include the identifier from the PMM and the current position of the vehicle.

4.4.2.3 Arrival Message (PMM-ARRIVE)

After the taxi or transit vehicle has replied to the traveler via a PMM-RSP, it will send a PMM-ARRIVE message to the traveler, which tells the traveler when the vehicle is expected to arrive at the traveler's location to pick them up and to provide the traveler with details about what vehicle to look for. When outside of DSRC range, the message is only re-sent if the expected arrival time changes by more than a configurable amount. Once the vehicle is within a configurable distance of the pickup location, it will no longer send the PMM-ARRIVE message via cellular, and broadcast the PMM-ARRIVE message via DSRC once every 5 seconds, until it reaches the travel group. Using DSRC allows the PMM-Arrive message to be sent at a greater frequency, allowing information to get to the mobile device in the timeliest manner.

Information included in a PMM-ARRIVE include the identifier from the PMM, the current position of the vehicle, the expected arrival time, and a visible description of the vehicle (for example, make, model, color, license plate, etc.).

4.4.2.3 Cancellation Message (PMM-CANCEL)

There may be a situation where a traveler needs to cancel a trip before a transit vehicle or taxi is able to fulfill the travel request. This may happen when the traveler has a change of plans, or the traveler receives more than one PMM-RSP message, and must cancel all but one of the trips. In this case, the mobile device will broadcast a PMM-CANCEL message.

Information included in a PMM-CANCEL is the identifier from the PMM.

4.4.3 Coordination Messages

Coordination Messages are generally used to initiate, maintain, and disband groups. These coordination messages are used to temporarily group travelers together into groups, and are sent between travelers via Wi-Fi Direct. Coordination allows a designated group leader to send messages regarding group needs (safety – PSM, and mobility – PMM), rather than individual messages from every member of the group. Coordination messages included in the Prototype Proof of Concept Field Demonstration include Coordination Request, Coordination Confirmation, Coordination Heartbeat, and Coordination Cancel.

4.4.3.1 Coordination Request

Coordination Request Messages are sent from a traveler to potential group leaders in the area that may be going to the same destination. A group leader mobile device that receives an Coordination Request Message will first check to see if the requesting traveler is heading toward the same destination (and conforms to the group leaders travel preferences), and if so, will send an updated PMM to the taxi or transit provider to figure out if the updated request can be accommodated.

4.4.3.2 Coordination Confirmation

If the group leader receives a PMM-RSP, acknowledging that the addition of the group member has been accepted, the group leader's mobile device can relay that response to the other traveler using a Coordination Confirmation Message. Aside from travelers providing mobility information and service providers accepting/rejecting travel requests, all computations and communications occur in the background.

4.4.3.3 Coordination Heartbeat

Once there are multiple travelers in a travel group, a Coordination Heartbeat Message is sent once every five seconds from the group leader to other group members to determine if group members are still in the vicinity. Once received, group members respond back to the group leader with a heartbeat acknowledgement. If acknowledgement messages are not received, the group leader can remove travelers from the group, and adjust mobility needs accordingly.

4.4.3.4 Coordination Cancel

Finally, once a travel group leader has been notified the ride has arrived (received PMM-ARRIVE), the group leader broadcasts a "Disband" coordination message to all members of the group. This indicates that the travel group has dissolved, and that devices of travelers can start to send personal safety and mobility-related message again.

4.4.4 Intersection RSU Messages

Messages sent from the intersection RSU include signal phase and timing (SPaT) and MapData (MAP) messages. These messages are sent via DSRC and are used by receiving entities for the purpose of location within the network and for applications that where signal controller status is needed.

For instance, a mobile device could use the information in the SPaT and MAP messages to support coordination when multiple pedestrians are on the same corner and want to use the same crosswalk, or for a more simple application, such as alerting the pedestrian when they are crossing against the pedestrian signal. While there are no applications in the Prototype Proof of Concept Field Demonstration that will utilize data in these messages, the ability of mobile devices and on-board devices to receive these messages will be tested. Once the ability to receive these messages has been confirmed, applications that use their data elements can be created and tested for follow-on projects.

4.4.4.1 Signal Phase and Timing (SPaT)

The SPAT message is used to convey the current status of one or more signalized intersections. Along with the Map Message (which describes a full geometric layout of an intersection) the receiver of this message can determine the state of the signal phasing and when the next expected phase will occur.

4.4.4.2 MapData (MAP)

The MAP message is used to convey many types of geographic road information. At the current time its primary use is to convey one or more intersection lane geometry maps within a single message. The map message content includes such items as complex intersection descriptions, road segment descriptions, high speed curve outlines (used in curve safety messages), and segments of roadway (used in some safety applications).

4.4.5 Overview of Messages

Table 4-1 on the following page summarizes the various message types that are included in the experimental prototype system. For each message type, the communications media, sending device type, receiving device type, and message frequency is listed. These correspond to the communications listed in black in Figure 4-1.

Table 4-1. Proof of Concept Field Demonstration Message Types

Message Type	Communication Media	Sent By	Received by/ Supports Apps on	Frequency
BSM	DSRC	In-Vehicle Device	Mobile Device, RSE	10 Hz
PSM	DSRC	Mobile Device	Vehicles, RSE	10 Hz
PMM	DSRC Cellular	Mobile Device Mobile Device	In-Vehicle Device, RSE In-Vehicle Device	one time one time
PMM-RSP	DSRC Cellular	In-Vehicle Device In-Vehicle Device	Mobile Device, RSE Mobile Device	one time one time
PMM-ARRIVE	DSRC Cellular	In-Vehicle Device In-Vehicle Device	Mobile Device, RSE Mobile Device	one time one time
PMM-CANCEL	DSRC Cellular	Mobile Device Mobile Device	In-Vehicle Device, RSE In-Vehicle Device	one time one time
Coordination Request	Wi-Fi Direct	Mobile Device	Mobile Device	one time
Coordination Confirmation	Wi-Fi Direct	Mobile Device	Mobile Device	one time
Coordination Heartbeat	Wi-Fi Direct	Mobile Device	Mobile Device	0.2 Hz
Coordination Cancel	Wi-Fi Direct	Mobile Device	Mobile Device	one time
SPaT	DSRC	RSE	Mobile Device, In-Vehicle Device	1 Hz
MAP	DSRC	RSE	Mobile Device, In-Vehicle Device	0.2 Hz
Travel Mode Detection	Bluetooth	In-Vehicle Device	Mobile Device	

Source: Battelle

Chapter 5 Prototype Proof of Concept Field Demonstration Site Plan

The purpose of the Prototype Proof of Concept Field Demonstration Site Plan is to describe the field demonstration experiments for demonstrating the operation of mobile devices and the operation of the coordination algorithm. The Prototype Proof of Concept Field Demonstration Site Plan will demonstrate traveler mobility benefits and coordinated transmission of PSMs via DSRC. The Prototype Proof of Concept Field Demonstration will include multiple mobile devices operating together with a connected light-duty vehicle and a connected transit vehicle. The connected transit and light-duty vehicle are capable of receiving and transmitting the same messages generated by the mobile devices. Travelers carrying mobile devices will safely transition from pedestrians to vehicle passengers and back throughout the demonstration as the target vehicles stops to collect and discharge passengers along their route of travel. Message reception by additional DSRC-capable mobile and/or roadside devices will be logged as a part of both demonstrations (coordinated and uncoordinated).

The Site Plan describes:

- Recruitment and identification of test participants and their roles and responsibilities
- Identification of training requirements for test participants and a description of how the training will take place
- Identification of required components and plan for conducting all stages of the Prototype Proof of Concept Field Demonstration Site Plan to include installation and removal of all in-vehicle devices (and identification of who is responsible); installation check out tests prior to the demonstration (to ensure required components are functional); and plans for a dry run before the field demonstration.
- Site plan layout to reflect location of test area at TFHRC, including driver routes, areas of operation of the prototype, and any infrastructure equipment
- Schedule that includes the planning, preparation, and test activities.

The Site Plan describes the elements of the demonstration including location of the test area, test participants, hardware and software components to be implemented for vehicles and travelers. The Site Plan compliments the Prototype Proof of Concept Field Demonstration Experimental Plan, presented in Chapter 6. Together, these two documents comprise the Prototype Proof of Concept Field Demonstration.

The project includes a demonstration at the TFHRC in McLean, VA for the verification of all demonstration elements. The Prototype Proof of Concept Field Demonstration is proposed to be performed over the course of two days. Under controlled test conditions, this test is intended as a field demonstration (and not a bench test or as a test emulation) showing an experimental design demonstrating the coordinated transmission of personal safety and personal mobility messages as well as mobile device coordination messages via various communications media including DSRC.

5.1 Test Participants Identification

Roles in the experiment include Test Director, Test Engineers, Test Support Staff, Test Observers, and Test Participants. Since this is a Prototype Proof of Concept Field Demonstration, it is expected that all test roles can be filled by Battelle employees and FHWA staff. The Test Director and Test Engineer roles will be filled by Battelle Staff that have been actively involved with the management, design, and development of the Mobile Devices project. Test support staff will be filled by Battelle staff that have experience working with connected vehicle systems. Test Observers will be comprised of FHWA Project Oversight Staff and/or stakeholders. Test participants will be selected and recruited from Battelle and from FHWA staff located at TFHRC. Additional Test Participants will be recruited by the GTM from interested and involved FHWA staff located at TFHRC. Table 5-1 below identifies each role, a preliminary list of people who could fill each role, and the responsibility of people filling each role.

Table 5-1. Test Roles and Responsibilities

Role	Name	Responsibility
Test Director	Joerg “Nu” Rosenbohm	Coordination of activities, and ensuring that activities are executed and completed according to the test schedule. Also guides all participants through each step of the test and demonstration. Persons in other roles will take direction from the Test Director
Test Engineers	Sudhakar Nallamothu Christopher Toth	Setting up test equipment and ensuring test equipment is working properly. Assists the Test Director in guiding all participants through each step of the test and demonstration.
Test Support Staff	Cary Vick Margaret Hailemariam	Will serve in support roles as assigned by the Test Director. This may include driving test vehicles and monitoring test equipment. Test support staff may provide guidance and explanation to Test Observers as needed.
Test Observers	Jon Obenberger Sampson Asare Others such as Test Engineers, Test Support Staff, etc.	Observing and confirming the results and outcomes for each step of the experiment. Test Observers may also be assigned the role of monitoring displays of messages received at Taxi and Transit Stops.
Test Participants	*At least 6 needed*	Assume the role of “travelers” and “passengers” who enter and exit vehicles and observe the mobile device displays.

Source: Battelle

5.2 Training Requirements

A detailed test scenario will be developed with detailed instructions for each step of the test scenario. The Test Scenario will describe what each participant is expected to do during each step. The role of each test participant will be identified in advance. Test Participants will be given the Test Scenario a week in advance of the test to provide ample time for review. The Test Day will begin with a training session and safety briefing, during which each participant will be briefed on what they should do during each step of the Test Scenario. Battelle team members will be prepared to provide guidance to FHWA and other Test Participants as required throughout the Test and Demonstration.

5.3 Demonstration Checkout/Checklist – Site Plan

Prior to the Prototype Proof of Concept Field Demonstration Experimental Test Plan execution at the FHWA TFHRC, several types of checks will be performed to ensure that the experimental test is conducted safely, the equipment will operate properly, and that data exchanged over the course of the experimental test is captured regardless of the communications media used for particular data exchanges. The following subsections provide a checklist for each type of checkout.

5.3.1 System Component Checklist

This section identifies the required components for conducting all stages of the Prototype Proof of Concept Field Demonstration including the installation and the removal of all in-vehicle devices, which includes the identification of the staff responsible for these activities. These checks encompass component level, the subsystem level, and the system level checkouts. They will be performed through the use of "dry runs" of the demonstration scenarios described in the following chapter by the Battelle Team prior to the initiation of the demonstration.

Checks will be performed on the following subsystems and components.

- Mobile Device Subsystem
    - Smartphone (Google Nexus 5X)
        - Bluetooth radio
        - Cellular radio
    - DSRC Communication Hardware (Arada LocoMate™ Mini 2 OBU)
    - Mobile Device Experimental Applications (MDEA) software
- Passenger Vehicle Subsystem
    - Computational Platform and User Interface (Google Nexus 5X)
        - Cellular radio
    - Vehicle Experimental Applications (VEA) software
    - DSRC Communication Hardware (Arada LocoMate™ ME OBU)
- Transit Vehicle Subsystem
    - Computational Platform and User Interface (Google Nexus 5X)
        - Cellular radio
    - Vehicle Experimental Applications (VEA) software
    - DSRC Communication Hardware (Arada LocoMate™ ME OBU)
    - Bluetooth Access Point (Estimote Beacon)
- Roadside Unit (RSU) Subsystem
    - Computational Platform (tablet – *to be determined*)
    - DSRC Communication Hardware (Arada LocoMate™ ME OBU)

- Cloud Service Subsystem
    - Computational Platform (Microsoft Windows Azure)

Component level checkouts will include:

- Power up each component
- Run diagnostics
- Activate application
- Run application with simulated input data
- Verify correct output/display from simulated data

Component level checkouts will all be completed satisfactorily in Battelle laboratories the week prior to deploying the experimental test plan equipment at the TFHRC.

Subsystem level checkouts will include:

- Assemble Mobile Devices Subsystem / Passenger Vehicle Subsystem / Transit Vehicle Subsystem / RSU Subsystem and install.
- Power up equipment and subsystem
- Verify data capture using diagnostics screen
- Run application with simulated input data
- Verify correct output/display from simulated data

Subsystem level checkouts will all be completed satisfactorily in Battelle laboratories the prior to deploying the experimental test plan equipment at the TFHRC.

System level checkouts will include:

- Power up equipment
- Verify components are functional (view diagnostic screen)
- Switch to operational display screen
- Finalize and save component, subsystem and system level configuration files.

System level checkouts will all be completed satisfactorily onsite at the TFHRC in the two (2) days prior to the experimental prototype system demonstration on December 15, 2016.

5.3.2 System Readiness Acceptance Criteria

Acceptance criteria will be developed as part of the Task 6 deliverable of this project to verify that all components of the system have been set up/installed properly, that all software is functional, and that the system is functional and is sending and/receiving the appropriate messages. A checklist will be created for each in-vehicle application and RSU equipment to verify the necessary steps are being followed for proper installation. Also, it will be important to verify that all software has been installed properly.

A benchmark acceptance test will be used to verify that software has been installed and working as intended. The test will verify that the devices are able to process data and adjust message parameters and communications media accordingly. Also, the test will be used to confirm that mobile devices and in-vehicle units are properly interfacing with users.

Finally, the ability of each piece of hardware (mobile device, in-vehicle unit, RSE) to send and receive messages through all media applicable to that piece of hardware is tested. A diagnostic test (a sequence of messages) will be devised to verify that data is being properly sent and received through all communications media to be used in the experiment by each device.

These acceptance criteria will be verified in advance of demonstration day. Verification of acceptance criteria will be reproduced again during the setup for the demonstration.

- All components will be developed and tested in the Battelle Laboratory
- Battelle will conduct a dry run of the test at Battelle Laboratory
- Battelle will conduct a dry run of the test at TFHRC after a successful completion of a dry run of the test at Battelle Laboratory
- Battelle will install and checkout all equipment two (2) days before the test day to make sure Prototype Proof of Concept Field Demonstration goes smoothly

5.3.3 Safety Checklist

There will be multiple moving vehicles during the demonstration, which greatly increases the risks for an incident. Battelle will assign a Safety Officer for the duration of the EPS demonstration, who will have the responsibility for coordinating all elements of the demonstration and the full authority to halt the demonstration at any time for any reason, if s/he believes that there is a safety risk. To further mitigate any risks, the following safety checklist will be exercised immediately prior to dry runs at the TFHRC and the execution of the EPS demonstration.

- Verify that all drivers, responders, and demonstration coordinators have working operational radio’s or similar devices for two-way communication to the Safety Officer.
- Verify that safety vests or other approved safety uniforms are being worn by all participants and observers who are outside of a vehicle.
- Verify an “all-clear” status of the track prior to initiation of any vehicle lap on the track.
- All Observers and Participants are accounted for and are at the appropriate position/location for the demonstration.
- Perform a safety briefing for all Observers and Participants.
- Verify that all vehicles, mobile devices, and RSU equipment are in full operational condition.
- Verify weather conditions support the demonstration (i.e., no lightning, visibility, or weather issues)
- Verify that the appropriate safety equipment is available including:
    - Water for participants and observers
    - Bathroom accommodations for participants and observers
    - Fire extinguishers

- Shelter from adverse weather events
- Rendezvous point should a site evacuation be needed.

5.4 Site Plan Layout

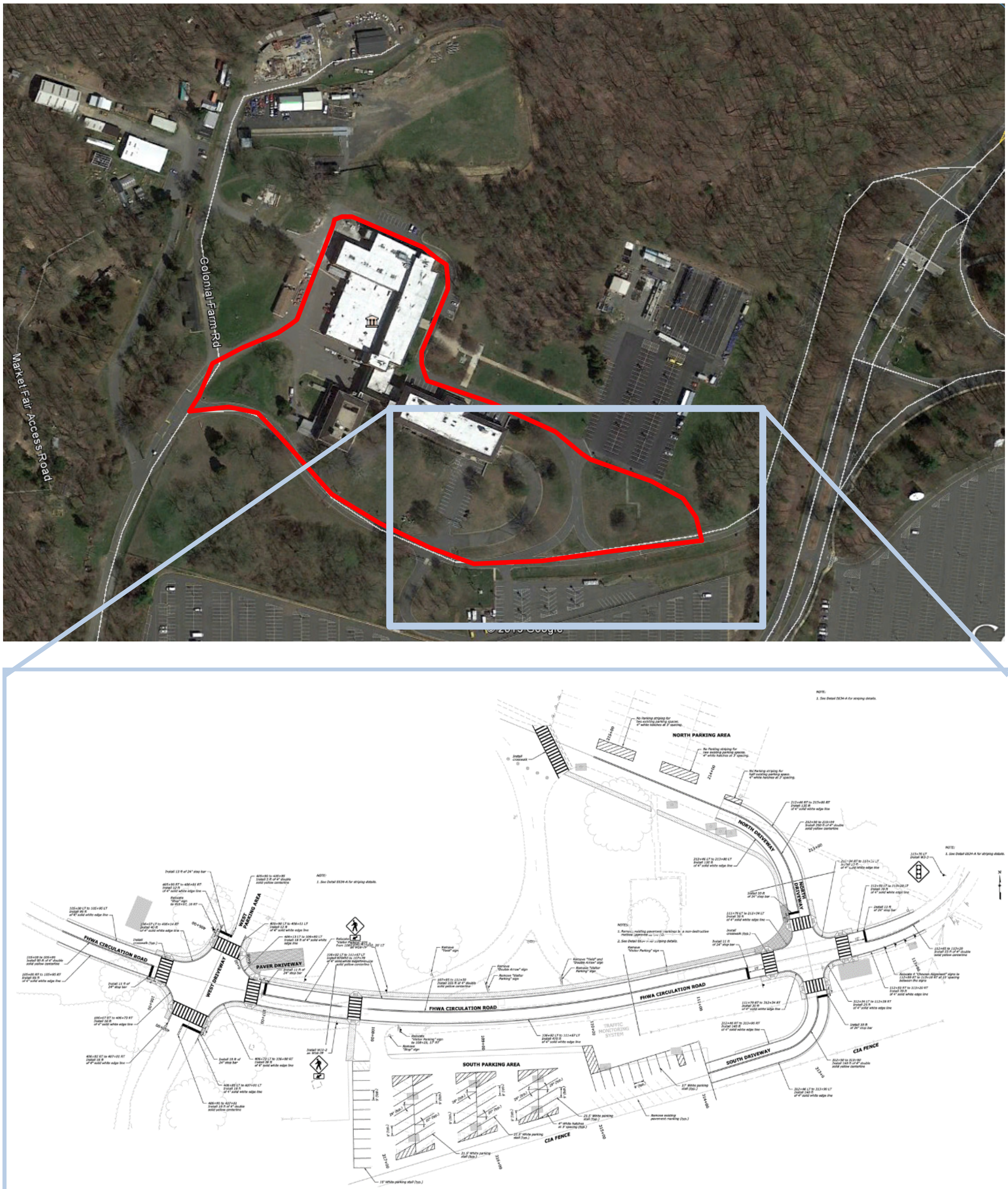
In order to facilitate the entire demonstration and testing process, the Battelle team will ensure that the facilities at the TFHRC are adequately prepared before testing. There will be a preliminary prototype demonstration Site Plan that will outline the essential areas where the experiment will take place on the facility. Battelle will use the existing TFHRC facilities/features where applicable to incorporate connected vehicle technology and execute tests. Additionally, the Site Plan will be comprised of a number of elements including Test Participants, Vehicles, Hardware, Software, and Layout Elements. All of these features will be used in conjunction to adequately experiment and study the hypotheses that have been proposed in this test plan.

5.4.1 Prototype Demonstration Site Plan

The Prototype Proof of Concept Field Demonstration will take place at the TFHRC. It is expected that the facility will provide an environment where the coordination of mobile devices can be tested in the context of the connected vehicle environment. The Experimental Plan contains a number of scenarios that will test that the system is operating as intended. It will be important to arrange the test facility so that the experiments can be properly conducted. The Experimental Plan calls for a taxi stop, a transit stop, a street-crossing location, and a RSU at the taxi and transit stop.

In order to determine where these elements will be located on the test facility, it is important to have an understanding of the facility's physical characteristics. The general layout of the facility is shown in the following satellite view in Figure 5-1. The facility has infrastructure on which connected vehicle equipment can be installed and a circle route can be established around the facility. The TFHRC test facility is currently undergoing renovations. It is expected that the current physical infrastructure and functionality will be expanded upon (not reduced), and will be capable of supporting the Prototype Proof of Concept Field Demonstration.

The red line in Figure 5-1 shows the circle route that could be used during the Prototype Proof of Concept Field Demonstration. It is important to note that the facility is being upgraded and is currently under construction, which will result in substantial changes to the site layout. Taking these changes into account will be necessary for developing the Site Plan for the Prototype Proof of Concept Field Demonstration. The design and location of facility upgrades at TFHRC are shown in the blue-framed portion of Figure 5-1.

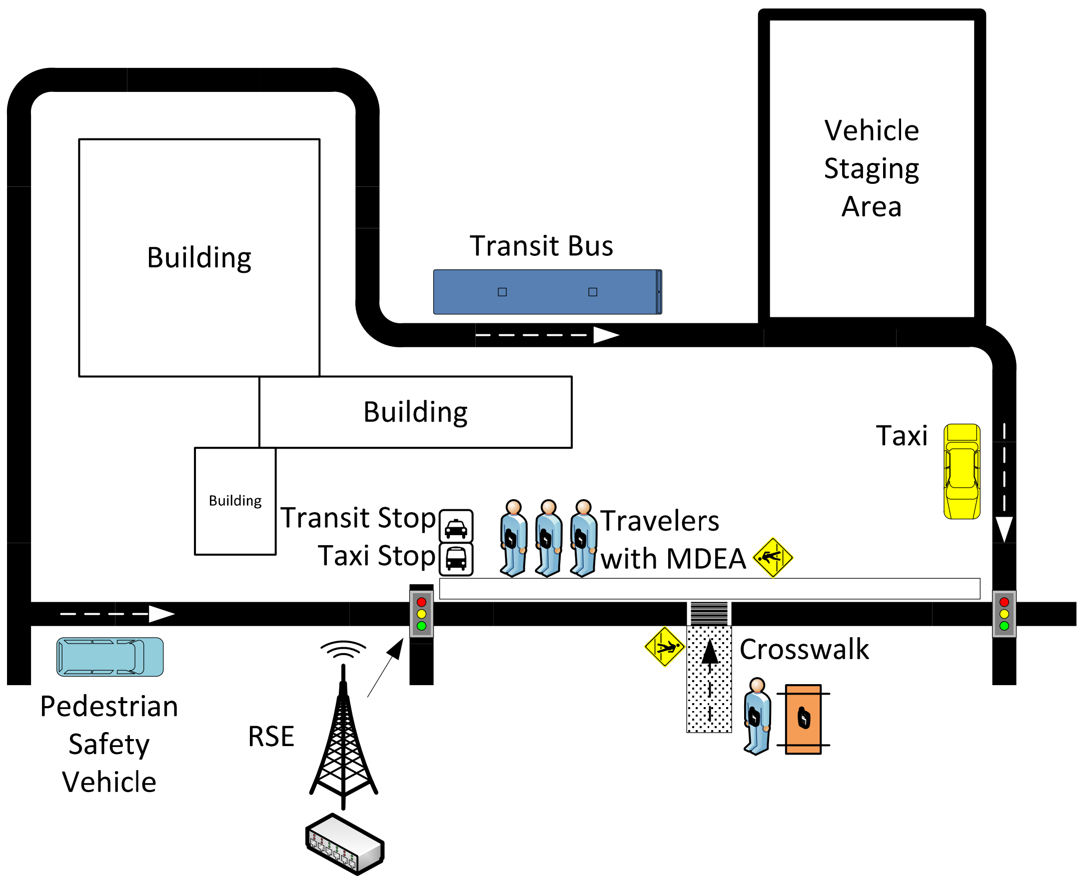


Source: Battelle

Figure 5-1. Turner-Fairbank Highway Research Center Test Site

The facility is located right next to the U.S. CIA headquarters, which might pose some challenges in terms of reliable cellular as well as other media coverage. Any such challenges will be discussed and addressed in conjunction with the project GTM and TFHRC staff prior to the demonstration date scheduling.

The circular route and areas where the prototype will operate are included in the Site Plan layout, which reflects the arrangement of physical infrastructure at TFHRC. The test site layout requirements are shown in the conceptual layout in Figure 5-2.



Source: Battelle

Figure 5-2. Site Plan Layout

5.4.2 Site Plan Elements

The Site Plan is comprised of five elements that will be utilized to execute the test plan's main objectives. These elements include Test Participants as identified in Table 5-1, Vehicles, Hardware, Software, and Layout Elements. Test Participants will play the roles of pedestrians and operators of the vehicles, of which include a Taxi, Transit Bus, and Pedestrian Safety Vehicle. The Test Participants will also be instructed to interact with hardware like Mobile Devices and On-board Equipment that will be installed with MDEA and VEA software, respectively. There are other hardware that will play a role in the environment such as the Bluetooth Presence Detector and Roadside equipment which is loaded with RSU Software. Crosswalks, Vehicle Staging Areas, and Vehicle Stops are physical elements of the layout that provide a geographical context for the scenarios enacted during the experimental process.

Test Participants

- Traveler – A traveler is the primary recipient of the safety and mobility benefits of the experimental application and interfaces with a mobile device when necessary. During pedestrian detection and pedestrian safety monitoring experiments where testing poses danger to a traveler, a traffic barrel will be used to simulate a pedestrian holding a mobile device.
- Driver – A driver operates a vehicle and interfaces with the vehicle on-board equipment, when necessary and only when it is safe to do so.

Vehicles

- Taxi – One of two vehicles that can respond to PMMs issued by a traveler. The taxi contains On-Board Equipment and is operated by a driver.
- Transit Bus - Second of two vehicles that can respond to PMMs issued by a traveler. The transit bus contains On-Board Equipment and is operated by a driver.
- Pedestrian Safety Vehicle – A vehicle that is used for pedestrian detection and pedestrian safety monitoring testing. The Pedestrian Safety Vehicle is outfitted with the Vehicle Experimental Application.

Hardware

- Mobile Device – A standard smartphone (Google Nexus 5X) outfitted with a DSRC radio, cellular service, and a Wi-Fi antenna. Each traveler in the experiment will carry a mobile device and interact with it in certain instances. Each mobile device will have the MDEA installed on it.
- On-Board Equipment – Performs the same function as the mobile device, but placed inside each vehicle. Also has a DSRC radio, cellular service, and will have the Vehicle Experimental Application installed on it. A driver interacts with the on-board equipment when necessary
- Presence Detector - a Bluetooth Beacon will broadcast a Bluetooth signal inside each vehicle for the purpose of presence detection.
- Roadside Unit (RSU) – located near the transit stop, taxi stop, and an intersection, the RSU is equipped with a DSRC radio and contains RSU software.

Software

- Vehicle Experimental Application (VEA) – Software installed on each vehicle containing applications being studied in this deployment.
- Mobile Device Experimental Application (MDEA) - Software installed on each mobile device containing applications being studied in this deployment.
- RSU Software – Software installed on the RSU that broadcasts SPaT and MAP messages via DSRC and records messages received via DSRC.

Layout Elements

- Transit/Taxi Stop – Location where travelers board the taxi and transit bus in the experiments. It is also the location where travel coordination occurs.
- Crosswalk – Location where the pedestrian detection experiments occur.
- Vehicle Staging Area – Location where vehicles can park and wait when needed during experimentation.

The actual demonstration will take place at the U.S. DOT's TFHRC in McLean, Virginia.

5.5 Demonstration Execution Timeline

Table 5-2 includes a schedule of the planning, preparation, and test activities.

Table 5-2. Prototype Proof of Concept Field Demonstration Plan Schedule

Activity	Expected Start Time	Expected Duration
Working with GTM and TFHRC staff to discuss space requirements as well as Cellular and DSRC coverage in test area within TFHRC	08/01/16	
Working with TFHRC staff and others participating in the demonstration to determine acceptable dates for the SSFTP	10/10/16	1 day
Coordinate with Transit Provider Renting of vehicles (2 transit and other vehicles)	11/07/16	
Get USDOT clearance to use those vehicles at TFHRC		
Sending of and arrival of equipment in McLean, VA (or Battelle Office in Crystal City, VA) - *milestone*	11/30/16	
Declaring Prototype readiness (milestone) – email from Battelle PM to GTM (Jon Obenberger)	12/02/16	
Installation and Testing of Roadside Equipment	12/05/16	2 hours
Installation and Testing of Vehicle Onboard Equipment	12/12/16	2 hours
Training of participants at TFHRC • Transit Operator • U.S.DOT Staff • Vehicle Operators • Pedestrians/Passengers	12/14/16	2 hours
Installation check prior to the demonstration (to ensure required components are functional)	12/13/16	2 hours
Dry run of Field Demonstration	12/13/16	3 hours
Last minute trouble-shooting, if needed	12/13/16	2 days
Execution of foundational tests that have failed during the prototype development (including GPS accuracy) – *1 hour?*		
Execution of Scenario 1 and Monitoring of the data collected	12/15/16	3 hours
Execution of Scenario 2 and Monitoring of the data collected	12/15/16	3 hours
Execution of Scenario 3 and Monitoring of the data collected	12/16/16	4 hours
Estimation of performance measures		
Prototype Proof of Concept Field Demonstration Post Mortem (a briefing with time for discussion) – *2 hours, the day after the Prototype Proof of Concept Field Demonstration execution*	12/19/16	2 days
Changes, adjustments, and key observations shall be documented in an updated Site Plan and Experimental Plan	12/16/16	4 days

Source: Battelle

Chapter 6 Prototype Proof of Concept Field Demonstration Experimental Plan

The purpose of the Prototype Proof of Concept Field Demonstration Experimental Plan is to describe the field demonstration experiments for demonstrating the operation of mobile devices in a connected vehicle environment and the operation of message coordination applications/algorithms. The Prototype Proof of Concept Field Demonstration will demonstrate the coordinated transmission of PSMs via DSRC, and a control demonstration of uncoordinated BSM transmission via DSRC. The Prototype Proof of Concept Field Test Experimental Plan will include multiple mobile devices coordinating with a non-connected and a connected light duty passenger-transporting vehicle (taxi or ride-share vehicle), and a connected transit bus. The connected taxi and transit bus are capable of transmitting messages that can be received by mobile devices and receiving messages generated by the mobile devices via DSRC and the cellular network, to be discussed later. The non-connected taxi is not capable of transmitting messages via DSRC but can send and receive messages via the cellular network. Travelers can coordinate travel to reduce the number of safety and mobility messages broadcast over DSRC. When the taxi or transit bus arrives at a pickup location and travelers carrying mobile devices enter the vehicle, mobile devices carried by the traveler will cease broadcasting safety and mobility messages once inside of the vehicle. The taxi or transit bus will discharge passengers along their route of travel, at which point the passengers (now pedestrians) will again broadcast safety messages. Message reception by additional DSRC-capable mobile and/or roadside devices will be logged as a part of the demonstrations that focus on coordinated and uncoordinated travel.

The Experimental Plan describes:

- Benefits of coordinated message generation and transmission
- Experimental Design
    - Hypotheses to be tested during the demonstration
    - Performance measures and targets
- Data Collection Plan
    - The process by which the data will be collected both by devices in the test as well as other technology deployed to receive and log transmitted messages
    - Data Quality Verification Processes
- Types of analyses that will be conducted on the data
- Risks and Mitigation
- Field Demonstration Experiments

The Experimental Plan concludes with a step-by-step description of field demonstration experiments that will be performed, including procedures, expected results, and verification methods. This Experimental Plan compliments the Prototype Proof of Concept Field Demonstration Site Plan.

As shown in the TOPR, Task 2 state of the practice[2], ConOps[3], and System Requirements Specification documents, there are many unanswered questions concerning how mobile devices will and can interact with connected vehicles to support safety and mobility of pedestrians, travelers, and vehicle passengers. This Experimental Plan describes field experiments designed to address the high-level objectives and key research questions associated with this project. In order to help develop detailed hypotheses and associated performance measures and targets, it will be beneficial to develop focused objectives that can be classified by the primary objectives.

6.1 Benefits of Coordinated Message Generation and Transmission

Prior to developing the experimental design and enumerating steps in the field demonstration experiments, it is important to emphasize the expected benefits of this project. An understanding of the project benefits provides an expectation of testing outcomes and experimental results. This will assist in developing hypotheses, performance measures, performance measure targets, and analyses that are performed to address the experimental components of this project.

It is well-known that large concentrations of mobile device users place a strain on communications via Wi-Fi, cellular and Bluetooth in dense urban areas and at major sporting events. Large concentrations of DSRC-equipped devices in the same vicinity have the potential to result in the degradation of DSRC communications performance. Thus, it is of interest in this project to assess scenarios where it is possible to reduce the number of messages sent via DSRC. Two concepts that will be analyzed during the Prototype Proof of Concept Field Demonstrationing include the coordination of travel between mobile device users and the ability to detect when a mobile device has entered a vehicle.

One of the major aspects of this project is the coordination of travel between mobile device users. The coordination of travel allows for a single point of contact between a transportation provider and a travel group (where all group members have the same itinerary) and the potential to reduce the number of PSMs broadcast, if the travel group members are in the same vicinity. That is, if there are a group of travelers waiting for a bus, only one designated member, the travel group leader, is required to communicate with the bus and broadcast a PSM for the group. Similar to the previous concept, this will reduce the number of safety messages and mobility messages that need to be sent over DSRC. In order to realize the benefits of travel coordination, it will be essential to demonstrate that the ad-hoc formation of travel groups can be accomplished using Wi-Fi-Direct communications media.

Another major aspect of this project is the detection of a mobile device entering a vehicle. PSMs being broadcast from a mobile device held by a passenger inside of a vehicle are difficult to interpret. In this case, the vehicle is broadcasting a BSM, and this message is essentially duplicated by the PSM from the mobile device, which is not necessary. Furthermore, since the PSM is inherently issued from a vulnerable road user (VRU), if it were broadcast from inside of a vehicle where the traveler is a passenger (and not a VRU), it would be difficult for surrounding vehicles to interpret and handle this message as intended. For instance, a pedestrian holding a mobile device enters a light-duty vehicle

[2] FHWA-JPO-15-TBD. Coordination of Mobile Devices: Technology and Standards Scan (June 19, 2015)
[3] FHWA-JPO-15-TBD. Concept of Operations Document for Coordination of Mobile Devices for Connected Vehicle Applications (July 16, 2015)

and the mobile device does not cease issuing PSMs. Other vehicles approaching the light-duty vehicle will receive the safety messages (issued from the mobile device) and issue a notification indicating that there is a pedestrian is the roadway. This may cause the driver of the approaching vehicle to react to a condition that is not present, possible leading to an unsafe condition. Additionally, receiving too many false notifications may result in drivers paying less attention to the notifications – reducing the likelihood the driver will react when a pedestrian is actually in the roadway.

The reasoning above establishes reason for why mobile devices must discontinue broadcast of PSMs when traveling in a vehicle – to prevent misinterpretation of PSM messages and to reduce the duplication of safety messages. Thus, it is essential for a mobile device to accurately detect its travel mode and to cease the broadcasting of PSMs when the detected travel mode changes to in-vehicle. It is critically important to demonstrate travel mode detection in order to realize the benefits accompanying the ceasing of broadcasting PSMs while in a vehicle.

The experiments described later in this section will demonstrate the ability of mobile devices to detect mode of travel as well as coordinate using Wi-Fi-Direct. Demonstrating these concepts will allow the benefits of the coordinated broadcasting PSMs and PMMs to be realized. Testing the limits of PMM coordination, quantifying DSRC channel congestion, and measuring the reduction in DSRC channel volume is beyond the scope of this project. However, it is expected that the larger the average group size, the more substantial the reduction of the burden on the DSRC channel. Group sizes are expected to be larger in situations where large number of pedestrians are present – fortunately, it is in situations such as these where large travel groups will provide the most benefit. The experiments conducted in the Prototype Proof of Concept Field Demonstration will demonstrate and test the concepts that will allow the benefits of coordinated message generation and transmission to be achieved.

The benefits that are expected to be demonstrated in the small-test extend beyond the coordination of travel between mobile devices and travel mode detection. Functionalities added to the RSU will allow for additional benefits to be demonstrated in the Prototype Proof of Concept Field Demonstration.

6.1.1 Other Benefits

The EPS includes other functionalities that will be beneficial for mobile device applications and for supporting traffic management activities. Both functionalities are enabled through the RSE. First, the RSE is capable of sending SPaT and MAP messages via DSRC. Demonstrating that mobile devices can receive and store the data included in these messages will provide evidence that the devices will be able to use this information to support applications that require this data. Examples of applications that could be supported include but are not limited to, pedestrian mobility, pedestrian in crosswalk warning, and coordination of travel at intersection crosswalks. The use of SPaT and MAP data in such applications is not tested in the Prototype Proof of Concept Field Demonstration, but the data that is contained in these messages is saved on the mobile device to show that a pedestrian-focused application could make use of the data.

Another functionality that is tested is the capability of the RSU to store all of the messages that it receives via DSRC. The storing of messages on-board the RSU simulates the ability of the RSU to send all of the messages that it receives to a TMC or another facility for managing the transportation network through a backhaul. A system at the TMC would parse the data contained in the messages, and perform any number of data processes and/or analysis techniques to output a data product that a system manager could use to manage demand on the network.

For example, BSM data could be processed in real-time to gain understanding of traffic conditions, or which approaches/movements at an intersection are not adequately served. In this case, the system manager could implement a congestion management solution or could adjust signal timing to improve operations. Alternatively, origin and destination data extracted from PMMs could be aggregated to establish a sequence of pick-up/drop-off locations for a variable route transit service that would service the travelers sending the PMMs. The transportation management utility of messages captured by the RSU is not tested in Prototype Proof of Concept Field Demonstration plan, but the ability of the RSU to store messages received via DSRC shows that transportation management activities have the ability to make use of various messages received via DSRC.

6.2 Experimental Design

Experiments must be designed to test the system to make sure it is working as intended. This section develops the hypotheses and performance measures that will be used in the Prototype Proof of Concept Field Demonstration. An experimental design summary is provided to relate the hypotheses, performance measures with the data that needs to be collected and the analyses that need to be performed to assess the ability of the system to operate properly and to obtain experimental results that will provide an understanding of the operating conditions that allow the system to function as intended.

6.2.1 Hypotheses

The next step in developing an evaluation plan for the Prototype Proof of Concept Field Demonstration is establish hypotheses that can be tested during the demonstration. Part of developing hypotheses is assessing which research questions are related to each objective. These research questions are defined in the Performance Work Statement. The hypotheses developed should be associated with the four main objectives and associated research questions and need to envelop the User Needs for the EPS developed in the ConOps. To support the objectives of this program, the Mobile Device Prototype Proof of Concept Field Demonstration Experiments will assess the hypotheses listed in Table 6-1. The hypotheses are categorized by the objectives they support and the research questions they answer.

Table 6-1. Relationship between Project Primary Objectives, Research Questions, Test Plan Objectives, and Hypotheses

Objective	Research Questions	Hypotheses
Demonstrate the potential for message coordination among mobile devices and transmission of messages Evaluate the potential benefit and potential issues associated with the transmission of probe and safety	• What policy and technical issues can be anticipated for dense connected vehicle/connected mobile device deployments? • What are the implications of a broadly unconstrained and uncoordinated deployment of mobile devices and connected vehicles operating in close proximity for connected vehicles applications?	**DSRC Channel Utilization Reduction Hypotheses** 1. The MDEA only broadcasts PSMs when in the vicinity of a vehicle broadcasting a BSM. 2. The overall MDEA DSRC message broadcast rate is lower during travel group coordination. 3. The MDEA can cease the broadcast of PSMs when in a vehicle. **Mobile Device PSM Broadcast Hypotheses** 4. The Mobile Device can broadcast a PSM a radius of 250 meters 10 Hz under clear, unobstructed conditions regardless of where

Objective	Research Questions	Hypotheses
messages from hand held mobile devices via alternative communications media.		the mobile device is located on the pedestrian's person or clothing.
Develop and test modifications to probe and safety messages for mobile devices that complement existing and emerging standards for messages from vehicles, and coordinate those proposed modifications with mobility application developers and standards development organizations.	• Are current messaging standards applicable to enable the practical incorporation of mobile devices supporting connected vehicle applications? • What improvements to existing mobile device messaging standards (or new approaches) can be identified to help achieve the highest potential impact from mobile devices for broader connected vehicle application deployment?	**Pedestrian Safety Hypotheses** 5. Vehicles OBUs can capture and process Mobile Device PSMs and issue warnings at sufficient distance for drivers to avoid imminent pedestrian collision regardless of where the mobile device is located on the pedestrian's person or clothing. 6. Mobile Devices can capture and process Vehicle BSMs and issue warnings in time for pedestrians to avoid imminent vehicle collision regardless of where the mobile device is located on the pedestrian's person or clothing. 7. Mobile Device applications can detect if a pedestrian is in a safe or unsafe zone. **Traveler Mobility Hypotheses** 8. The VEA can coordinate taxi travel requests from an MDEA 9. The VEA can coordinate transit travel requests from an MDEA 10. The traveler can receive arrival updates from a taxi or transit vehicle
Create and demonstrate potential methods for coordinating safety and mobility messaging linking mobile devices carried by pedestrians into light and transit vehicles that may be capable of generating one or more related safety and mobility messages.	• Can protocols or other methods be developed that coordinate the generation of safety and mobility-related messages among multiple mobile devices transported within connected vehicles as well as with the connected vehicle itself? • Do these coordination protocols have a practical benefit in enhancing mobility and safety of connected vehicle applications in potential large-scale connected vehicle deployments where many devices are vehicles may be located in close proximity?	**Transportation Mode Detection Hypotheses** 11. The MDEA can detect when a traveler transitions from a pedestrian to a light duty vehicle or from a light duty vehicle to a pedestrian. 12. The MDEA can detect when a traveler transitions from a pedestrian to a transit vehicle or from a transit vehicle to a pedestrian. **Travel Coordination Hypotheses** 13. The MDEA can coordinate, maintain, and cancel travel with another MDEA via Wi-Fi-Direct.
Evaluate the ability of RSU equipment for supporting	• Can an RSU send SPaT messages to a mobile device?	**SPaT and MAP Hypotheses**

Objective	Research Questions	Hypotheses
applications on mobile devices and traffic management activities.	• Can an RSU send MAP messages to a mobile device? • Can an RSU receive messages via DSRC and send them to a TMC where they can be processed for management purposes?	14. The RSU can broadcast a SPaT and MAP message via DSRC that can be received by mobile devices and on-board equipment. **RSU Data Capture Hypotheses** 15. The RSU can store all messages received via DSRC.

Source: Battelle

6.2.2 Performance Measures and Targets

Performance measures are categorized in the subsections below according to the hypothesis they support (developed in Section 6.2.1).

6.2.2.1 DSRC Channel Utilization Reduction Performance Measures

A major focus of this project is to reduce the number of messages sent over DSRC communications media. Reducing the number of messages sent via DSRC will prevent the likelihood of channel congestion issues, which may result in the degradation of safety and mobility benefits that are expected from CV systems. Thus, transmission frequency of PSMs has been identified as a performance measure that can be used to quantify the reduction in the number of messages sent via DSRC.

Transportation mode detection and travel coordination between mobile device users are both precursors for the ceasing of the broadcast of PSMs via DSRC. That is, a mobile-device does not need to continue to send PSMs when it is in a vehicle or when it is part of a travel group (not the group leader). The expected result is that only mobile devices outside of a vehicle that are a group leader or that have not coordinated travel (e.g., walking) should broadcast PSMs. The number of PSMs sent from a mobile device via DSRC can be determined by reading the experimental logs of each mobile device. After a mobile device has entered a vehicle or has coordinated travel with another mobile device (as determined by reading the experimental logs), it should cease broadcasting PSMs. The reduction in PSMs can also be confirmed by reading the logs of the RSU – which should be a short distance (less than 10 m) away from the location where coordination and the mode transition are expected to occur.

In the case where two or more travelers are in the same place at the same time with the same travel itinerary, coordination between the mobile devices of the travelers is possible. Prior to coordination, the overall rate at which PSMs are being sent is equivalent to the total number of travelers. After coordination, only the group leader should broadcast PSMs – an overall rate of 10 Hz.

A travel group disbands prior to entering a vehicle (taxi or transit) and all members will be issuing PSMs for a brief period, between the end of coordination and entering the vehicle. Thus, prior to entering the vehicle, the overall rate at which PSMs are being sent is equivalent to the total number of travelers. If a device detects that it has entered a vehicle, it should cease broadcasting PSMs. After all devices have been detected as entering the vehicle, no PSMs should be broadcast (i.e. the target PSM broadcast rate is 0 Hz).

Finally, mobile devices only broadcast PSMs when a vehicle is in range (J2945-9). In this context, *in range* refers to the distance between the pedestrian and a vehicle at which the mobile device broadcasts PSMs and is a function of the vehicle speed (defined in Appendix C). The equation in Appendix C can be used to determine that a mobile device will broadcast PSMs when within 100 meters of a vehicle moving at 25 mph (11.18 m/s). Prior to the vehicle being within 100 meters of a stationary mobile device, the mobile device should not issue PSMs (i.e. the target PSM broadcast rate is 0 Hz). Once the vehicle is within 100 meters of the mobile device, the mobile device is expected to broadcast PSMs at a rate of 10 Hz.

Performance measures and performance measure targets associated with DSRC Channel Utilization are listed in Table 6-2.

Table 6-2. DSRC Channel Utilization Reduction Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
1. The MDEA only broadcasts PSMs when in the range of a vehicle broadcasting a BSM.	PSM Message Rate prior to vehicle being in range	0 Hz	MDEA Log – GPS Location MDEA Log – BSM received Occurrence MDEA Log – PSM send occurrences	Determine if vehicle is out of range of mobile device, based on vehicle speed Analysis of PSMs sent while vehicle is out of range.
	PSM Message Rate while vehicle is in range	10 Hz	MDEA Log – GPS Location MDEA Log – BSM received Occurrence MDEA Log – PSM send occurrences	Determine if vehicle is in range of mobile device, based on vehicle speed Analysis of PSMs sent while vehicle is in range
2.The overall MEDA DSRC message broadcast rate is lower during travel group coordination	PSM Message Rate prior to coordination	N x 10 Hz	MDEA Log – Coordination Status MDEA Log – PSM send occurrences	Determine Coordination Status Analysis of PSMs sent while not part of travel group
	PSM Message Rate after coordination (travel group leader)	10 Hz	MDEA Log – Coordination Status MEDA Log – PSM send occurrences	Determine Coordination Status Analysis of PSMs sent while part of travel group (travel group leader)
	PSM Message Rate after coordination (travel group member)	0 Hz	MEDA Log – PSM send occurrences	Analysis of PSMs sent while part of travel group (travel group member)
3. The MDEA can cease the broadcast of PSMs when in a vehicle.	PSM Message Rate prior to detection of entering vehicle	N x 10 Hz	MDEA Log – Travel Mode Status MEDA Log – PSM send occurrences	Determine that mobile device is not in a vehicle Analysis of PSMs sent while not in a vehicle
	PSM Message Rate after detection of entering vehicle	0 Hz	MDEA Log – Travel Mode Status MEDA Log – PSM send occurrences	Determine that mobile device is in a vehicle Analysis of PSMs sent while in a vehicle

Source: Battelle

Where N = number of travelers in the travel group. *Note: Range is defined as the distance between a mobile device and a vehicle when the mobile device broadcasts PSMs. The relationship between a vehicle's speed and the range at which a mobile device broadcasts PSMs is described in* Appendix C*.*

6.2.2.2 Mobile Device PSM Broadcasting Performance Measures

It will be important to gain an understanding of the functional ability of the mobile device to broadcast messages on the DSRC communications spectrum. Mobile Device PSM Broadcasting tests are primarily concerned with the ability for a receiving device (a vehicle-based system) to receive PSMs sent from a mobile device. Both the MDEA and the VEA keep a log of the messages sent and received. As in other tests, messages sent by the broadcasting device can be paired with messages received by the receiving device to determine if messages are being received properly. Thus, a performance measure that can be used to determine if messages are being received properly is the PSM reception rate. PSMs are planned to be sent at a rate of 10 Hz, and thus, this is the expected rate at which PSMs are received under ideal circumstances. However, there are factors that will limit the ability of messages to be sent and received. If possible, the test should control for certain factors that are expected to be outside of the scope of this project, such as the impact of foliage, various weather conditions, and fixed objects between the sending and receiving devices. Ideally, the test is performed in clear conditions where there is an open line-of-sight between the sending and receiving devices. Other factors that may impact the message reception rate include the distance between devices and the location of the mobile device on the pedestrian. These factors will be experimental variables. The test will be performed when the vehicle and mobile device are placed at various ranges up to 300 meters (less than 10 meters, 50, 100, 150, 200, 250, 300 meters). This is the maximum distance at which DSRC devices are expected to be able to function under ideal unobstructed conditions to support V2V safety applications[4]. It is expected that DSRC broadcasting range be the same for supporting V2P safety applications (such as the pedestrian safety monitoring feature being tested in this project). The test will be performed with the mobile device placed at various locations on the pedestrian (in-hand, in-pocket, and in purse/backpack). To ensure consistent results, the transmit power of the mobile device will be held constant, at the maximum allowable transmit power. Performing the test at 50 meter increments should allow the relationship between range, mobile device placement location, and PSM broadcasting performance to be assessed.

Performance measures designed to test the broadcast range of a mobile devices at various ranges are listed in Table 6-3. Conditions when the target broadcast rate can be achieved will be beneficial in determining the operational limitations of mobile devices.

[4] FHWA-JPO-15-218. Status of the Dedicated Short-Range Communications Technology and Applications

Table 6-3. Mobile Device PSM Broadcasting Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
4. The Mobile Device can broadcast a PSM a radius of 250 meters 10 Hz under clear, unobstructed conditions, regardless of where the mobile device is located on the pedestrian's person or clothing	PSM Message Rate at a distance of less than 10 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
	PSM Message Rate at a distance of 50 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
	PSM Message Rate at a distance of 100 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
	PSM Message Rate at a distance of 150 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
	PSM Message Rate at a distance of 200 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
	PSM Message Rate at a distance of 250 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
	PSM Message Rate at a distance of 300 m	**10 Hz**	RSU Log – PSM receive occurrences	The rate at which PSMs are received by the RSU will be assessed. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.

Source: Battelle

6.2.2.3 Pedestrian Safety Performance Measures

One of the difficulties of developing performance measures for the pedestrian safety applications in the experimental system is the unknown effects of positioning error. Due to the critical nature of pedestrian safety, it is important to make sure that pedestrians and vehicles can be located accurately enough to warn drivers of an impending collision with a pedestrian while limiting the number of false positive warnings.

The algorithms that determine if/when an advisory, alert, and/or warning are issued will only work as well as the input data will allow. The relationship between the positioning ability of mobile devices/vehicles and the accuracy of the issuance of advisory, alert, and/or warning needs to be studied to gain an understanding of the implications of positioning has on pedestrian safety applications.

Technical literature[5] indicates that the best position accuracy that can be achieved with conventional GPS and DGPS technology is three (3) meters. Battelle investigators found that Ublox Precise Point Precision[6] GPS position accuracy was adequate to support which-lane level accuracy of approximately 2 m during a test period, but drift in GPS position prevented them from achieving where-in-lane level accuracy. However, these units required systems comparable to laptop computers in size with similar power requirements. While they could be integrated in mobile devices in the future, this level of accuracy does not appear to be available in mobile device form factors at current mobile device price points.

It is known that cell phones use Assisted GPS (A-GPS), which integrate location information from cellular systems with GPS to achieve higher position accuracy than can be achieved from conventional GPS alone. These systems are reported to have accuracy of five (5) to eight (8) meters. Accuracy, in reference to GPS positioning, refers to the radius within which a device is able to position itself 68% of the time – which means that about 32% of locations will fall outside of the specified accuracy radius. Most roadway lanes are three (3) to four (4) meters wide, which is somewhat similar to the accuracy of mobile device positioning accuracy. However, it is unknown what mobile device positioning accuracy is required to support the presented safety applications. This risk associated with the uncertainty of a mobile device to accurately position itself is discussed in detail in Section 6.5.1.

Prior investigations by Battelle and others suggest that mobile devices may be able to achieve road level position accuracy necessary to support driver advisories. Battelle investigators tested the ability of connected vehicle technology to meet the communication and position accuracy needs for first responder safety similar to pedestrian safety as part of the Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Project. In that project, Battelle investigators developed the R.E.S.C.U.M.E. connected vehicle system, messages, and applications which delivered advisories, alerts, warnings and stop! Warnings pertaining to first responder personnel in the roadway ahead.[7] The system also included a system to alert and warn first responder when a vehicle approaching the incident zone is being operated unsafely. While the R.E.S.C.U.M.E. project emphasized safety of first responders during roadside incidents, the project results and conclusions demonstrated the capability of connected vehicle technology to meet the fundamental needs for pedestrian safety, namely:

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[5] Beauregard, S. and H. Haas, Pedestrian Dead Reckoning: A Basis for Personal Positioning. International University Bremen School of Engineering and Science. Proceedings of the 3rd Workshop on Positioning, Navigation, and Communication. 2006.
[6] https://www.u-blox.com/sites/default/files/products/documents/NEO-7P_ProductSummary_(UBX-13003350).pdf
[7] FHWA-JPO-14-TBD. R.E.S.C.U.M.E. Prototype Acceptance Test Summary

1. Vehicle OBUs can capture and process DSRC messages and issue warnings at sufficient distance for drivers to avoid imminent pedestrian collision.
2. Mobile Devices can capture and process DSRC messages and issue warnings in time for pedestrians to avoid imminent vehicle collision.

For this project, an imminent collision is defined as a collision that will occur if the driver and/or pedestrian continue on their respective paths – an imminent collision can be avoided if either the driver or pedestrian take proper evasive action (stopping and/or changing direction) when presented with a warning (the highest level notification).

The communications and computational latency of the R.E.S.C.U.M.E. connected vehicle system – which was sufficiently low enough to warn drivers in time to stop oncoming vehicles and avoid collision – is expected to be very similar to that of the experimental system. Whether the communications and computational latency is sufficing for pedestrian safety will be investigated during the demonstration test; however, communications and computational latency are not expected to be the main challenges to issue pedestrian advisory, alerts, or warnings in time.

Testing will be required to determine if they can reliably support lane level accuracy needed to support driver alerts of pedestrians in unsafe zones (advisory) or imminent collision (warning). It is expected that additional development of technology, performed under a future project, will likely be necessary for mobile devices to achieve the accuracy necessary to support driver warnings when a collision with a pedestrian is imminent.

The requirements development process for this project generated the following set of requirements for driver and pedestrian safety warnings:

1. A driver needs to be advised when pedestrians are present.
2. A driver needs to be alerted when pedestrians are within the approaching vehicle's trajectory and are located in an unsafe zone.

   Note: An "Unsafe Zone" is in a lane in which vehicle may travel including a roadway shoulder, a pedestrian crosswalk, or any area within one meter of the edge of the roadway. A "Safe Zone" is on a sidewalk or zone in which a vehicle must cross a physical obstacle to collide with pedestrian.
3. A driver needs to be warned when pedestrians are within the approaching vehicle's trajectory and are in the vehicle's lane of travel.
4. A pedestrian needs to be advised, if they are within an approaching vehicle's trajectory.
5. A pedestrian needs to be alerted if they are within an approaching vehicle's trajectory and the pedestrian is in an unsafe zone.
6. A pedestrian needs to be warned if they are within an approaching vehicle's trajectory and the pedestrian is in the vehicle's lane of travel.

Table 6-4 summarizes the corresponding needs of GPS accuracy and latency performance necessary to support these applications. Latency is comprised of communications latency and processing/display latency. Communications latency is the amount of time it takes for a message to be sent to the time it is received by a second device. Vehicle-to-Vehicle Safety needs require communications latency of less than 100 milliseconds.[8] Processing/Display latency is the amount of time it takes the second device to parse, process, and display outputs from any application(s) running on the mobile device. Previous projects such as INFLO have been successfully demonstrated with

[8] FHWA-JPO-15-218. Status of the Dedicated Short-Range Communications Technology and Applications

processing/display latency values targets of less than 500 milliseconds.[9] Thus, the overall latency should be less than 600 milliseconds. Latency will be measured by reading the timestamps of the logs on mobile devices and in-vehicle devices. Devices are synchronized (discussed Section 6.3.1) so that the timestamps of the events listed above can be compared from device to device. Accuracy and Latency targets are suggested based upon prior analysis and experiments[10,11].

Table 6-4. GPS Accuracy andLatency Requirements for Pedestrian Safety Applications

Application	Message Type	Vehicle GPS Accuracy*	Mobile Device GPS Accuracy*	Latency
Vehicle	Advisory	Which Road Level	Which Road Level	<600 ms
Vehicle	Alert	Which Lane Level	Which Lane Level	<600 ms
Vehicle	Warning	Where-in-Lane Level	Which Lane Level	<600 ms
Pedestrian	Advisory	Which Road Level	Which Lane Level	<600 ms
Pedestrian	Alert	Which Lane Level	Which Lane Level	<600 ms
Pedestrian	Warning	Where-in-Lane Level	Which Lane Level	<600 ms

* For the purposes of this investigation

Source: Battelle

Where-in-Lane Level Position Accuracy is defined as a R95 Probability of horizontal position accuracy of less than or equal to 0.5 meters,

Lane Level Position Accuracy is defined as a R95 Probability of horizontal position accuracy of less than or equal to 2 meters and Road Level Position Accuracy is defined as a R95 Probability of horizontal position accuracy of less than or equal to 7.5 meters.

R95 is defined as the radius of a circle centered on the true antenna position that contains 95% of the actual GPS measurements.

Pedestrian safety hypotheses include the ability of the system to provide adequate notice for drivers and mobile devices of impending vehicle-pedestrian collisions and the ability of the mobile device to properly place itself in a map.

The distance between a mobile device and a vehicle when an advisory or a warning is issued to a pedestrian and a driver is one of the performance measures that is used to determine if the pedestrian safety features of the system are working as intended. As explained in Appendix C, the distance between a mobile device and a vehicle at which these messages should be displayed is dependent on vehicle speed. Thus, it will be important to control for the vehicle speed when performing pedestrian safety experiments. The speed of the vehicle is expected to be constant.

[9] FHWA-JPO-14-171. Report on Detailed Requirements for the INFLO Prototype.

[10] FHWA-JPO-15-248 through FHWA-JPO-15-254. Vehicle-to-Infrastructure (V2I) Safety Applications Performance Requirements, Vols 1 to 7.

[11] FHWA-JPO-14-TBD. R.E.S.C.U.M.E. Prototype Acceptance Test Summary

When a mobile device and a vehicle have intersecting paths, the distance between the vehicle and the anticipated intersection at which an advisory and warning should be displayed to the pedestrian and the driver is 58 meters, and 50 meters, respectively (for a vehicle moving at 25 mph, see Appendix C). It is important to include the false negative rate as a performance measure for this test, to assess the likelihood a message is not displayed to a pedestrian or a driver when it should have been. When a mobile device and a vehicle do not have intersecting paths, advisories and warnings should not be issued to the driver or the pedestrian. In this case, the false positive rate will be used as a performance measure, which assesses the likelihood that a pedestrian or driver receives an advisory or warning, although no collision is imminent (as the pedestrian is in a safe zone).

The ability of a mobile device to properly position itself in a map will also be tested. There are two primary types of locations that are of interest for testing pedestrian location ability – safe and unsafe zones. The performance measure devised for this test is the correct position rate, or the percentage of times a mobile device is able to correctly identify which zone it is in. Because variability is expected in GPS readings, it will be of interest to place the mobile device is various locations in both safe and unsafe zones so that relationships between the actual location of the mobile device and the correct position rate can be assessed. The further into an unsafe zone the mobile device is placed, the greater the likelihood the mobile device should be detected as being in the unsafe zone. As the mobile device is placed closer to the border between the safe and unsafe zone, the less likely the mobile device will position itself in the unsafe zone. Performance measures developed for this test assume a normally distributed mobile device positioning error of 3 meters. That is, if the mobile device positioning accuracy is better than 3 meters, then the target should be met.

Performance measures and performance measure targets associated with Pedestrian Safety are listed in Table 6-5.

Table 6-5. Pedestrian Safety Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
5.Vehicles OBUs can capture and process Mobile Device PSMs and issue warnings at sufficient distance for drivers to avoid imminent pedestrian collision, regardless of where the mobile device is located on the pedestrian's person or clothing	Distance at which Advisory is displayed (mobile device)	**100 m**	MDEA Log – Advisory Display MDEA Log – GPS Location MDEA Log – BSM Location	Based on the speed of the vehicle (in the BSM received by the mobile device), assess the distance at which an Advisory is issued.
	Distance at which Alert is displayed (mobile device)	**58 m**	MDEA Log – Alert Display MDEA Log – GPS Location MDEA Log – BSM Location	Based on the speed of the vehicle (in the BSM received by the mobile device), assess the distance at which an Alert is issued.
	Distance at which Warning is displayed (mobile device)	**50 m**	MDEA Log – Warning Display MDEA Log – GPS Location MDEA Log – BSM Location	Based on the speed of the vehicle (in the BSM received by the mobile device), assess the distance at which a warning is issued.
	Advisory False Alarm Rate (mobile device)	**1%**	MDEA Log – Advisory Display MDEA Log – GPS Location MDEA Log – BSM Location	Based on the speed of the vehicle (in the BSM received by the mobile device), assess the Advisory false alarm rate.
	Alert False Alarm Rate (mobile device)	**1%**	MDEA Log – Alert Display MDEA Log – GPS Location MDEA Log – BSM Location	Based on the speed of the vehicle (in the BSM received by the mobile device), assess the Alert false alarm rate.
	Warning False Alarm Rate (mobile device)	**1%**	MDEA Log – Warning Display MDEA Log – GPS Location MDEA Log – BSM Location	Based on the speed of the vehicle (in the BSM received by the mobile device), assess the Warning false alarm rate.
	Latency (message sent from vehicle to display on mobile device)	**500 ms**	VEA Log – BSM Send Occurrence MDEA Log – Warning Display	Analyze time difference between PSM received and the message display time. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
6. Mobile Devices can capture and process Vehicle BSMs and issue warnings in time for pedestrians to avoid imminent vehicle collision regardless of where the mobile device is located on	Distance at which Advisory is displayed (mobile device)	**100 m**	VEA Log – Advisory Display VEA Log – GPS Location VEA Log – PSM Location	Based on the speed of the vehicle (in the VEA Log), assess the distance at which an Advisory is issued.
	Distance at which Alert is displayed (vehicle)	**58 m**	VEA Log – Alert Display VEA Log – GPS Location VEA Log – PSM Location	Based on the speed of the vehicle (in the VEA Log), assess the distance at which an Alert is issued.
	Distance at which Warning is displayed (vehicle)	**50 m**	VEA Log – Warning Display VEA Log – GPS Location VEA Log – PSM Location	Based on the speed of the vehicle (in the VEA Log), assess the distance at which a warning is issued.

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
the pedestrian's person or clothing.	Advisory False Alarm Rate (vehicle)	**1%**	VEA Log – Advisory Display VEA Log – GPS Location VEA Log – PSM Location	Based on the speed of the vehicle (in the VEA Log), assess the Advisory false alarm rate.
	Alert False Alarm Rate (vehicle)	**1%**	VEA Log – Alert Display VEA Log – GPS Location VEA Log – PSM Location	Based on the speed of the vehicle (in the VEA Log), assess the Alert false alarm rate.
	Warning False Alarm Rate (vehicle)	**1%**	VEA Log – Warning Display VEA Log – GPS Location VEA Log – PSM Location	Based on the speed of the vehicle (in the VEA Log), assess the Warning false alarm rate.
	Latency (message sent from mobile device to display in vehicle)	**500 ms**	MDEA Log – PSM Send Occurrence VEA Log – Warning Display	Analyze time difference between BSM received and the message display time. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.
7. Mobile Device applications can detect if a pedestrian is in a safe or unsafe zone.	Mobile Device In-Road Positioning Rate (2.0 m in roadway)	**>91%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed in the roadway – mobile device location is properly classified if it positions itself in an unsafe zone.
	Mobile Device In-Road Positioning Rate (1.0 m in roadway)	**>75%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed in the roadway – mobile device location is properly classified if it positions itself in an unsafe zone.
	Mobile Device In-Road Positioning Rate (0.5 m in roadway)	**>63%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed in the roadway – mobile device location is properly classified if it positions itself in an unsafe zone.
	Mobile Device In-Road Positioning Rate (0.5 m from roadway edge)	**<37%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed outside of the roadway – mobile device location is properly classified if it positions itself in a safe zone.
	Mobile Device In-Road Positioning Rate (1.0 m from roadway edge)	**<25%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed outside of the roadway – mobile device location is properly classified if it positions itself in a safe zone.
		<10%	MDEA Log – GPS Location	

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
	Mobile Device In-Road Positioning Rate (2.0 m from roadway edge)		MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed outside of the roadway – mobile device location is properly classified if it positions itself in a safe zone.
	Mobile Device In-Road Positioning Rate (3.0 m from roadway edge)	**<3%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed outside of the roadway – mobile device location is properly classified if it positions itself in a safe zone.
	Mobile Device In-Road Positioning Rate (4.0 m from roadway edge)	**<1%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed outside of the roadway – mobile device location is properly classified if it positions itself in a safe zone.
	Mobile Device In-Road Positioning Rate (5.0 m from roadway edge)	**<1%**	MDEA Log – GPS Location MDEA Log – Safe/Unsafe Zone Status MDEA Log – MAP Message Contents	Analyze percentage of properly classified safe/unsafe zone detections. The device is placed outside of the roadway – mobile device location is properly classified if it positions itself in a safe zone.

Target distances based on vehicle moving at 25 mph (11.18 m/s)

Source: Battelle

6.2.2.4 Traveler Mobility Performance Measures

Travelers will be able to use their mobile device to coordinate travel over various communications media available to their mobile devices. Tests are performed to assess a traveler's mobility needs – arranging travel with a taxi and a transit bus using DSRC and cellular communications media. The performance measures developed to assess travel mobility focus on the ability for travelers to coordinate travel with a taxi or transit vehicle via DSRC or cellular. Sequences of messages that are expected to occur were first presented in the System Requirements event sequence diagrams.

Coordinating travel is accomplished when a PMM is successfully sent from a mobile device to a vehicle (taxi or transit bus) and the mobility request is presented to the vehicle driver and the vehicle changes its coordination status. Once the driver manually accepts the mobility request, a PMM-RSP is successfully sent back to the mobile device, and the mobile device displays an acknowledgement and changes its coordination status.

There are certain instances when a traveler may need to cancel a mobility request – if the traveler changes their mind about taking the trip or if the traveler receives PMM-RSP messages from multiple transportation providers. The PMM-Cancel message is sent from the mobile device to the taxi or transit vehicle. When the message is received, the vehicle should no longer be coordinated with the traveler. Processing of the PMM-Cancel message is considered successful if when received the travel coordination status between the vehicle and the device it is responding to is canceled on the MDEA and the VEA.

Finally, after coordination, the vehicle sends a PMM-Arrive message to the traveler to indicate the expected time of arrival. The message is sent only if the arrival time changes beyond a certain threshold. Processing of the PMM-Arrive message is considered successful if when received by the mobile device, the mobile device updates the expected arrival time of the vehicle that is responding to its mobility request.

The System Requirements specifies that travel coordination occurs both over DSRC and cellular. Thus, it will be important to test the ability to coordinate travel over both communications media. The same vehicle experimental application (VEA) will be installed on the taxi and transit vehicle, so both types of vehicles will need to be tested – the physical effects of the vehicle on the ability to communicate are unknown, especially over DSRC communications media.

Performance measures and performance measure targets associated with Traveler Mobility are listed in Table 6-6.

Table 6-6. Traveler Mobility Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
8.The VEA can coordinate taxi travel requests from an MDEA	PMM Successful Processing Rate (Taxi) – DSRC	**100%**	MDEA Log – PMM Send occurrence MDEA Log – PMM contents Experimental Log – Information entered into Mobile Device by Traveler VEA Log – PMM Receive occurrence	Analyze the percentage of PMM messages properly processed by in-vehicle devices.
	PMM-RSP Successful Processing Rate (Taxi) – DSRC	**100%**	Experimental Log – Driver Acceptance VEA Log – Driver acceptance VEA Log – PMM-RSP Send occurrence MDEA Log – PMM-RSP Receive occurrence MDEA Log – Coordination Status Experimental Log – Coordination Success Display	Analyze the percentage of PMM-RSP messages properly processed by mobile devices.
	PMM-Cancel Successful Processing Rate (Taxi) – DSRC	**100%**	MDEA Log – PMM-Cancel Sent Occurrence VEA Log - PMM-Cancel Received Occurrence	Analyze the percentage of PMM-Cancel messages properly processed by in-vehicle devices.
	PMM Successful Processing Rate (Taxi) – Cellular	**100%**	MDEA Log – PMM Send occurrence MDEA Log – PMM contents Experimental Log – Information entered into Mobile Device by Traveler VEA Log – PMM Receive occurrence	Analyze the percentage of PMM messages properly processed by in-vehicle devices.
	PMM-RSP Successful Processing Rate (Taxi) – Cellular	**100%**	Experimental Log – Driver Acceptance VEA Log – Driver acceptance VEA Log – PMM-RSP Send occurrence MDEA Log – PMM-RSP Receive occurrence MDEA Log – Coordination Status Experimental Log – Coordination Success Display	Analyze the percentage of PMM-RSP messages properly processed by mobile devices.

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
	PMM-Cancel Successful Processing Rate (Taxi) – Cellular	**100%**	MDEA Log – PMM-Cancel Sent Occurrence VEA Log - PMM-Cancel Received Occurrence	Analyze the percentage of PMM-Cancel messages properly processed by in-vehicle devices.
9.The VEA can coordinate transit travel requests from an MDEA	*same as previous hypothesis*	*same as previous hypothesis*	*same as previous hypothesis*	same as previous hypothesis
10.The traveler can receive arrival updates from a taxi or transit vehicle	PMM-Arrive Successful Processing Rate (Taxi) – DSRC	**100%**	VEA Log – PMM-ARRIVE Send occurrence MDEA Log – PMM-ARRIVE Receive occurrence	Analyze the success rate of receiving a PMM-Arrive message.
	PMM-Arrive Successful Processing Rate (Taxi) – Cellular	**100%**	VEA Log – PMM-ARRIVE Send occurrence MDEA Log – PMM-ARRIVE Receive occurrence	Analyze the success rate of receiving a PMM-Arrive message.
	PMM-Arrive Successful Processing Rate (Transit) – DSRC	**100%**	VEA Log – PMM-ARRIVE Send occurrence MDEA Log – PMM-ARRIVE Receive occurrence	Analyze the success rate of receiving a PMM-Arrive message.
	PMM-Arrive Successful Processing Rate (Transit) – Cellular	**100%**	VEA Log – PMM-ARRIVE Send occurrence MDEA Log – PMM-ARRIVE Receive occurrence	Analyze the success rate of receiving a PMM-Arrive message.

Source: Battelle

6.2.2.5 Transportation Mode Detection Performance Measures

One aspect of this project is the detection of a traveler's transition between modes. A traveler's smartphone will have an indication of when a taxi or transit vehicle is in his or her vicinity, but the moment the traveler enters the vehicle must be precise. The ability to detect when the mobile device is in a vehicle is important because this has implications for turning off the broadcasting of PSMs - which essentially duplicate the vehicle's BSM and are difficult to interpret when broadcast from a vehicle.

Smartphones contain a suite of sensors, along with communications components that can be used to detect if a traveler, carrying a smartphone, has transitioned from a pedestrian (waiting for a vehicle) to a vehicle occupant. Smartphone sensors and components that could be used to detect this transition were outlined in the Task 2 Technology Scan. Sensor and Bluetooth-based methods will be used to detect this mode transition.

The sensor-based method will utilize data coming from the smartphone's accelerometer, gyroscope, barometer, etc. to identify signatures in the data that correspond to the traveler moving from a standing/sitting position at the pickup location, walking to the vehicle, and entering the vehicle. The method that assesses transportation mode could be an in-house developed algorithm that continuously runs in the background on-board the mobile device, or a Google Activity Recognition API12 which relies on consistent internet access.

Alternatively, a Bluetooth beacon can be used to detect the time when a passenger transitions from a pedestrian to an occupant. Bluetooth Beacons can be used to precisely locate a Bluetooth-enabled smartphone device. For the experiment, one or more Bluetooth Beacon could be placed near the entrance of a vehicle (transit bus) or near the center of a vehicle (car, taxi). The traveler will enter the vehicle, enter the range of the Bluetooth Beacon, which the smartphone would detect to indicate the traveler has entered the vehicle. An application on a smartphone could detect the presence of a Bluetooth Beacon, and use the relative signal strength indicator (RSSI) to estimate the distance the smartphone is away from the Bluetooth Beacon. Properly calibrating a distance estimation algorithm will be essential for the Bluetooth Beacon method to detect mode transitions. For the purposes of Bluetooth presence detection, a mobile device is considered present in a vehicle if it is able to determine that it is within the vehicle based on the signal strength of one or more Bluetooth readers.

Performance measures and performance measure targets associated with Mode Detection are listed in Table 6-7. The performance measure for the detection of a mode transition from a pedestrian to a vehicle (and vice-versa) will be based on detecting the transition before the vehicle has moved a target distance and the detection of mode transition will be expected to occur in a given amount of time of the pedestrian entering the vehicle. Mode detection is expected to occur within the vehicle moving 3 meters on 90 percent of mode change transitions – as specified in the System Requirements. Mode transition detections are expected to occur within 10 seconds of the traveler entering the vehicle 90 percent of the time – as specified in the System Requirements. It is also important to address the likelihood that a mode transition is incorrectly sensed. Because there is the potential for false alarms, they are included as a performance measure.

[12] https://developers.google.com/android/reference/com/google/android/gms/location/ActivityRecognition

Table 6-7. Transportation Mode Detection Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
11. The MDEA can detect when a traveler transitions from a pedestrian to a light duty vehicle or from a light duty vehicle to a pedestrian.	Mode Transition Detection (on-foot to passenger) distance traveled by vehicle after passenger enters vehicle (Taxi)	3 meters	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters	Assess change in "Travel Mode Status" before the vehicle has traveled more than 3 meters.
	Mode Transition Detection Time (on-foot to passenger) (Taxi)	10 seconds	MDEA Log – Travel Mode Status Experimental Log – Time that traveler enters vehicle	Assess change in "Travel Mode Status" after the pedestrian enters the vehicle.
	Mode Transition Detection (on-foot to passenger) False Positive Rate (Taxi)	10%	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters	Assess false positive rate of transition detection.
	Mode Transition Detection (passenger to on-foot) distance traveled by vehicle after passenger exits vehicle (Taxi)	3 meters	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters	Assess change in "Travel Mode Status" before the vehicle has traveled more than 3 meters.
	Mode Transition Detection Time (passenger to on-foot) (Taxi)	10 seconds	MDEA Log – Travel Mode Status Experimental Log – Time that traveler enters vehicle	Assess change in "Travel Mode Status" after the pedestrian exits the vehicle.
	Mode Transition Detection (passenger to on-foot) False Positive Rate (Taxi)	10%	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters Experimental Log – Time when traveler exits vehicle	Assess false positive rate of transition detection.

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
12. The MDEA can detect when a traveler transitions from a pedestrian to a transit vehicle or from a transit vehicle to a pedestrian.	Mode Transition Detection (on-foot to passenger) distance traveled by vehicle after passenger enters vehicle (Transit vehicle)	3 meters	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters	Assess change in “Travel Mode Status” before the vehicle has traveled more than 3 meters.
	Mode Transition Detection Time (on-foot to passenger) (Transit Vehicle)	10 seconds	MDEA Log – Travel Mode Status Experimental Log – Time that traveler enters vehicle	Assess change in “Travel Mode Status” after the pedestrian enters the vehicle.
	Mode Transition Detection (on-foot to passenger) False Positive Rate (Transit vehicle)	10%	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters	Assess false positive rate of transition detection.
	Mode Transition Detection (passenger to on-foot) distance traveled by vehicle after passenger exits vehicle (Transit vehicle)	3 meters	MDEA Log – Travel Mode Status	Assess change in “Travel Mode Status” before the vehicle has traveled more than 3 meters.
	Mode Transition Detection Time (passenger to on-foot) (Transit vehicle)	10 seconds	MDEA Log – Travel Mode Status Experimental Log – Time that traveler enters vehicle	Assess change in “Travel Mode Status” after the pedestrian exits the vehicle.
	Mode Transition Detection (passenger to on-foot) False Positive Rate (Transit vehicle)	10%	MDEA Log – Travel Mode Status Experimental Log – Time at which vehicle has traveled 3 meters Experimental Log – Time when traveler exits vehicle	Assess false positive rate of transition detection.

Source: Battelle

6.2.2.6 Travel Coordination Performance Measures

The ability to support traveler mobility applications without the use of DSRC communications media is expected to reduce the number of messages sent via DSRC. In order to do this, a mobile device must be able to coordinate travel with other mobile devices in the vicinity. The two travelers must share a similar itinerary for the coordination to occur. In the case where two travelers have the same itinerary, they should be able to coordinate using only Wi-Fi-Direct communications media. Upon the processing of coordination messages, a group leader is determined. Only the mobile device of this group leader continues to broadcast PSMs.

The coordination of travel can be verified by reading the logs of the mobile devices that are coordinating travel. It can be verified that coordination is properly occurring by assessing the mobility requirements (destination) of each mobile device user, reading the logs of each mobile device, and assessing the sequences and content of coordination messages exchanges between the mobile devices. In order to verify that coordination of travel has occurred, several events must be recorded in the experimental log of the coordinating mobile devices:

1. Sending of a Coordination Request (Mobile Device 2 experimental log)
2. Receipt of Coordination Request (Mobile Device 1 experimental log)
3. Verification of matching destinations (Mobile Device 1 experimental log)
4. Sending of updated PSM (Mobile Device 1 experimental log)
5. Receipt of PMM-RSP (Mobile Device 1 experimental log)
6. Sending of Coordination Confirmation (Mobile Device 1 experimental log)
7. Receipt of Coordination Confirmation (Mobile Device 2 experimental log)

There are several various sequences of messages that are sent during the coordination of two or more mobile devices. Performance measures and tests for these hypotheses will be set up to determine if the mobile devices take the correct actions when various coordination messages are received.

The first message exchange that will be tested is the Coordination Request Message. This message is sent by a mobile device looking for a travel group leader. Once the travel group leader receives the Coordination Request Message, there are two possible outcomes. The first outcome is that the trip itinerary details contained in the message match with the trip itinerary details of the travel group leader. In this case, the proper response would be the issuance of a coordination acceptance message, begin to issue coordination heartbeat message, and a change in the ‘number of group members’ element in the PSM sent by the group leader. In the case where the trip itinerary details do not match, the proper response of the group leader is to continue with current operations. Performance measures are defined based on the percentage of successful responses once the coordination request message is received.

Next the Coordination Acceptance Message is tested. There is only one possible response from the receiving device that indicates that the system is operating properly. The receiving device must relay a message to the traveler indicating successful travel coordination. While the receiving mobile device should also cease broadcasting PSMs, this will be included as part of another test – a test designed to reduce DSRC channel utilization.

Once the travel group is formed, the coordination Heartbeat message is sent from the travel group leader to other mobile devices in the group. The only proper response for a group member mobile device is the response of a heartbeat response message. If the travel group leader mobile device received a heartbeat response message, then it does nothing. However, if no heartbeat response message is received, then the group leader mobile device shall update the PMM and update the 'number of group members' element in the PSM automatically. If a heartbeat messages is received, but the travel group member is too far away from the group leader, then the group leader mobile device should update the 'number of group members' in the PSM, but not issue a PMM update.

A travel group member or the group leader may wish to cancel their trip, in which case a coordination cancel message would be sent. There is one possible outcome of receiving a coordination cancel message that indicates that the system is working as intended. When the message is received, the group leader mobile device shall update the PMM and update the 'number of group members' element in the PSM.

When the vehicle that picks up the travel group arrives, the group disbands prior to entering the vehicle. In this case, a Coordination disband message is sent from the group leader to all other members of the group.

The range over which these messages are expected to be able to be transmitted can be determined by considering dimensions of the waiting area for transit vehicles. A waiting area can contain numerous traveler amenities (e.g. shelter, benches, waiting pad, etc.), which creates a large area for where coordination between travelers will need to occur. It will be important for coordination messages to be transmitted throughout the waiting area – tests should be designed so that coordination can occur in large waiting areas. The Central Ohio Transit Authority (COTA) Bus Stop Design Guide13 specifies the dimensions of elements that comprise bus stops in Columbus, OH. The total dimensions of a bus waiting area can be as large as 347 inches (high-capacity bus shelter: 239 inches, ADA-compliant landing pad: 60 inches, area between the bus stop and the landing pad: 48 inches) by 119 inches. The largest distance between any two points (opposite corners) of this area is 367 inches (9.32 meters). Thus, when conducting coordination tests, mobile devices will be placed 10 meters apart, as this should be sufficient for coordination between travelers in large transit waiting areas.

Performance measures and performance measure targets associated with Travel Coordination are listed in Table 6-8.

[13] http://www.cota.com/COTA/media/PDF/BSSIP/Bus-Stop-Design-Standards_web-version.pdf

Table 6-8. Travel Coordination Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
13. The MDEA can coordinate, maintain, and cancel travel with another MDEA via Wi-Fi-Direct.	Coordination Message Performance - Wi-Fi-Direct communication media at a distance of 10 meters or less.	100%	Experimental Log – Mobile Device (1) Position Experimental Log – Mobile Device (2) Position MDEA (1) Log – Coordination Request Sent Occurrence MDEA (1) Log – Coordination Request Contents MDEA (2) Log – Coordination Request Received Occurrence MDEA (1) Log – Coordination Request Contents	Determine percentage of Coordination Request messages received by mobile devices when within 10 meters of another coordinating mobile device. Assess message contents for consistency.
	Coordination Request Message Successful Processing Rate (trip details match)	100%	MDEA (1) Log – Coordination Request Sent Occurrence MDEA (2) Log – Coordination Request Received Occurrence MDEA (2) Log – Coordination Confirmation Sent Occurrence MDEA (2) Log – Coordination Heartbeat Sent Occurrence MDEA (2) Log – PSM Sent Contents	Determine percentage of Coordination Request messages properly processed by mobile devices.
	Coordination Request Message Successful Processing Rate (trip details do not match)	100%	MDEA (1) Log – Coordination Request Sent Occurrence MDEA (2) Log – Coordination Request Received Occurrence MDEA (2) Log – Coordination Confirmation Sent Occurrence MDEA (2) Log – Coordination Heartbeat Sent Occurrence MDEA (2) Log – PSM Sent Contents	Determine percentage of Coordination Request messages properly processed by mobile devices.

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
	Coordination Acceptance Message Successful Processing Rate	100%	MDEA (2) Log – Coordination Acceptance Sent Occurrence MDEA (1) Log – Coordination Acceptance Received Occurrence MDEA (1) Log – Coordination Acceptance Notification MDEA (1) Log – Coordination Heartbeat Received Occurrence	Determine percentage of Coordination Acceptance messages properly processed by mobile devices.
	Coordination Heartbeat Response Message Successful Processing Rate (coordination heartbeat response received)	100%	MDEA (1) Log – Coordination Heartbeat Response Sent Occurrence MDEA (2) Log – Coordination Heartbeat Response Received Occurrence	Determine percentage of Coordination Heartbeat Response messages properly processed by mobile devices.
	Coordination Heartbeat Response Message Successful Processing Rate (coordination heartbeat response not received)	100%	MDEA (1) Log – Coordination Heartbeat Response Sent Occurrence MDEA (2) Log – Coordination Heartbeat Response Received Occurrence MDEA (2) Log – PSM Sent Contents	Determine the rate that a group leader mobile device handles the situation where a Coordination Heartbeat Response message is not received.
	Coordination Cancel Message Successful Processing Rate	100%	MDEA (2) Log – Coordination Cancel Response Sent Occurrence MDEA (1) Log – Coordination Cancel Response Received Occurrence	Determine percentage of Coordination Cancel messages properly processed by mobile devices.
	Coordination Disband Message Successful Processing Rate	100%	MDEA (2) Log – Coordination Disband Sent Occurrence MDEA (1) Log – Coordination Disband Received Occurrence	Determine percentage of Coordination Disband messages properly processed by mobile devices.

Source: Battelle

6.2.2.7 SPaT and MAP Performance Measures

As stated previously, it is important to test if a mobile device is capable of receiving and storing the contents of SPaT and MAP messages sent by the RSU via DSRC. Experimental logs of the RSU will be read to determine if the RSU is sending SPaT messages at a frequency of 1 Hz and MAP messages at a frequency of 0.2 Hz.

A mobile device must receive SPaT and MAP messages prior to the pedestrian arriving at an intersection to support pedestrian safety applications. The distance at which these messages must be received are dependent on the location of the RSU and the dimensions of the intersection. Assuming the RSU is placed at the same location as the traffic signal controller cabinet on one corner of the intersection, the furthest point from the RSU at which a pedestrian must be able to receive SPaT and MAP messages is at the corner of the intersection opposite the traffic signal controller. The design of the intersection and its approaches affect this corner-to-corner distance. Thus, the distance at which messages need to be received should be designed based on a large design intersection. Intersection approaches. Figure 6-1 shows an example of a large intersection where a pedestrian standing over 300 feet (91.5 meters) from the RSU would need to be able to receive SPaT and MAP messages. This intersection exhibits approaches with up to seven lanes, and an approximately 65 foot median. To design for intersections that may be even larger, the test will be performed at a distance of 100 meters.

Source: Battelle

Figure 6-1. Large Intersection in Tysons, Virginia

Factors that affect range include transmit power, antenna location, foliage, weather, and other fixed objects. To control for these factors, the RSU will broadcast SPaT and MAP messages via DSRC at the maximum allowable transmit power and will be tested under clear conditions with no physical obstructions between the RSU and mobile device.

The experimental logs of the mobile device can be read to determine that the mobile device is capable of receiving the messages at the same frequency with which they are sent with 99% success rate while standing at a distance of 100 meters or less from the RSE. Furthermore, the mobile device experimental logs should contain output that indicates that information in the messages are being parsed properly.

Performance measures and performance measure targets associated with the SPaT and MAP messages are listed in Table 6-9.

Table 6-9. SPaT and MAP Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
14. The RSU can broadcast a SPaT and MAP message via DSRC that can be received by mobile devices.	SPaT Message Performance - DSRC communication media at a distance of 100 meters or less.	**100%**	RSU Log – SPaT sent Occurrence RSU Log – SPaT message Content Experimental Log – RSU Position Experimental Log – Mobile Device Position MDEA Log – SPaT message receipt MDEA Log – SPaT message content	Determine percentage of SPaT messages received by mobile devices when within 100 meters of RSE. Assess message contents for consistency.
	MAP Message Performance - DSRC communication media at a distance of 100 meters or less	**100%**	RSU Log – MAP message send Occurrence RSU Log – MAP message Content Experimental Log – RSU Position Experimental Log – Mobile Device Position MDEA Log – MAP message receive occurrence MDEA Log – MAP message content	Determine percentage of MAP messages received by mobile devices when within 100 meters of RSE. Assess message contents for consistency.

Source: Battelle

6.2.2.8 RSU DSRC Messages Receipt Performance Measures

As stated previously, it is important to test if the RSU is capable of receiving and storing the contents of all types of messages sent by mobile devices and vehicles via DSRC. The RSU contains both a log that captures the occurrences of the sending and receipt of messages along with a separate memory where all messages received are stored in raw format. The log is used for testing and evaluation purposes while the memory for storing raw message content simulates the ability of messages to be received by a TMC (where they would undergo further processing). Similar to previous tests involving RSEs, it is expected that 99% of messages sent via DSRC in a 100 meter radius can be received and stored on the RSE. This is based on the corner-to-corner distance in large intersections. This can be verified by reading the experimental logs from mobile devices and vehicles to generate a list of messages that were sent via DSRC and compare this against experimental logs from the RSU which contains the list of messages received by the RSU.

Factors that affect range include transmit power, antenna location, foliage, weather, and other fixed objects. To control for these factors, the mobile device will broadcast various messages via DSRC at the maximum allowable transmit power and will be tested under clear conditions with no physical obstructions between the RSU and mobile device.

Three performance measures have been designed to verify that the RSU is operating as intended. Message receipt performance will test the ability of the RSU to read and interpret data from incoming messages. Message save performance refers to the ability of the RSU to do store the message after it is received - this simulates the ability of the RSU to send the messages to a TMC. Memory performance refers to the ability of the RSU to have storage capacity sufficient enough to save all messages throughout the testing process. Memory performance is measured by assessing the total size of all messages received throughout the testing process and comparing against the size of the storage capacity of the RSU. This will not only ensure that an RSU has sufficient memory, it will provide insight into the required CV data processing capability for a TMC, once TMC-related applications are developed.

Performance measures and performance measure targets associated with RSU Receipt of DSRC Messages are listed in Table 6-10.

Table 6-10. RSU DSRC Messages Receipt Performance Measures and Targets

Hypothesis	Performance Measure	Target	Data Log – Data Type	Analysis
15. The RSU can store all messages received via DSRC.	DSRC Message Receipt/Saved Performance	99%	MDEA Log – all occurrences of messages sent via DSRC MDEA Log – message contents Experimental Log – Mobile Device Position Experimental Log – RSU Position RSU Log – Message Received Occurrence RSU Log – Message Contents	Assess percentage of messages received from mobile devices within 100 meters of RSE. Assess message contents to make sure they are consistent.
	Memory Performance	RSU Log Storage Capacity	RSU Log – Stored Message Data	Assess size of messages and rate at which on-board storage is used.

Source: Battelle

6.3 Data Collection

As detailed in the Experimental Design Summary (Section 6.2), the data to be collected are related to the messages sent/received by various devices in the system, as well as a record of events and sensor-related information. Messages, events, and sensor data can be captured on data logs on various devices in the system. Key experimental data from the Prototype Proof of Concept Field Demonstration will be uploaded to the research data exchange (RDE). If possible, this data will be uploaded to the RDE in real-time, but may also be archived and uploaded to the RDE. The results of some elements of the experiment, such as the display of messages or entry of information that require verification by Test Engineers is included in an experimental observation log. The various type of logs are explained in Table 6-11.

The various messages, events, sensor information and observations that are recorded in the logs are listed and described in Table 6-12. Each item captured in the data logs are coupled with a time stamp of when they occur. A given data type is applicable to one or more of the log types from Table 6-11.

Table 6-11. Description of Data Logs Utilized in the Evaluation

Log Type	Description
Experimental Log	A log of field observations throughout the course of the execution of the experiment.
MDEA Log	A log of various messages sent, messages received, events, sensor data, and GPS data on the mobile device.
RSU Log	A log of various messages sent and messages received on the RSE.
VEA Log	A log of various messages sent, messages received, events, and GPS data on the in-vehicle device.

Source: Battelle

Table 6-12. Description of Data Types Collected in Data Logs

Data	Description
Advisory Display	An event in a log noting the time when an advisory is displayed
Alert Display	An event in a log noting the time when an alert is displayed
BSM Contents	Values of data elements contained in a BSM
BSM received Occurrence	An event in a Log noting the time when a BSM is received.
Coordination Confirmation Received Occurrence	An event in a Log noting the time when a Coordination Confirmation Message is received.
Coordination Confirmation Sent Occurrence	An event in a Log noting the time when a Coordination Disband Message is broadcast.
Coordination Disband Received Occurrence	An event in a Log noting the time when a Coordination Disband Message is received.
Coordination Disband Sent Occurrence	An event in a Log noting the time when a Coordination Disband Message is broadcast.
Coordination Request Contents	Values of data elements contained in a Coordination Request Message
Coordination Request Received Occurrence	An event in a Log noting the time when a Coordination Request Message is received.

Data	Description
Coordination Request Sent Occurrence	An event in a Log noting the time when a Coordination Request Message is broadcast.
Coordination Status	An event recorded in a log that identifies the coordination status of the MDEA. Possible values include uncoordinated and coordinated.
Coordination Success Display	The observed message that verifies that mobility request was successful.
Display PMM-RSP	An event in a log noting the time when the acceptance of travel is displayed
Driver acceptance	The observed time when a driver accepts a mobility request
GPS Accuracy	Raw GPS accuracy data.
GPS Location	Raw GPS latitude and longitude data.
Heartbeat Message Received Occurrence	An event in a Log noting the time when a Heartbeat Message is received.
Heartbeat Message Sent Occurrence	An event in a Log noting the time when a Heartbeat Message is broadcast.
Information entered into Mobile Device by Traveler	The observed information entered into a mobile device be a traveler for creating a mobility request
MAP message content	Values of data elements contained in a MAP Message
MAP message receive occurrence	An event in a Log noting the time when a MAP Message is received.
MAP message send Occurrence	An event in a Log noting the time when a MAP Message is broadcast.
Mobile Device Position	The observed position of the mobile device
PMM contents	Values of data elements contained in a PMM
PMM Receive occurrence	An event in a Log noting the time when a PMM is received.
PMM Send occurrence	An event in a Log noting the time when a PMM is broadcast.
PMM-ARRIVE Send occurrence	An event in a Log noting the time when a PMM-ARRIVE is broadcast.
PMM-RSP Contents	Values of data elements contained in a PMM-RSP
PMM-RSP Receive occurrence	An event in a Log noting the time when a PMM-RSP is received.
PMM-RSP Send occurrence	An event in a Log noting the time when a PMM-RSP is broadcast.
PSM Receive Occurrence	An event in a Log noting the time when a PSM is received.
PSM send occurrence	An event in a Log noting the time when a PSM is broadcast.
RSU Position	The observed position of the RSE
Safe/Unsafe Zone location	The observed location of the mobile device. Possible values include safe or unsafe.
Safe/Unsafe Zone Status	An event recorded in a log that identifies the safe/unsafe status of the MDEA. Possible values include safe and unsafe.
SPaT message Content	Values of data elements contained in a SPaT Message
SPaT message receipt	An event in a Log noting the time when a SPaT Message is received.
SPaT sent Occurrence	An event in a Log noting the time when a SPaT Message is broadcast.
Time at which vehicle has traveled 10 meters	The observed time when a vehicle has traveled 10 meters
Time when traveler enters vehicle	The observed time when a traveler enters a vehicle.
Travel Mode Status	An event recorded in a log that identifies the travel mode status. Possible values include in-vehicle and out-of-vehicle.
Warning Display	An event in a log noting the time when a warning is displayed

Source: Battelle

6.3.1 Processes for Verifying Data Quality

Analysis of message logs will be performed to verify the format and content of the messages and confirm that messages received are identical to messages sent. Coordinated Universal Time (UTC) will be used to time stamp all messages sent and received from all devices. In many cases, logs from multiple devices are needed for an analysis. This will be particularly useful for ensuring sequences of events occur in the proper order and to perform accurate latency assessments. Thus, it will be important to make sure the device clocks are synchronized using network time (all devices are being connected to the Internet) to minimize the likelihood of obtaining inaccurate results.

6.4 Data Analysis

As described above, the data to be collected are primarily logs containing information about the various messages sent and received by the different devices and components of the system. It will be important to be able to assess each performance measure developed for the hypotheses. This is accomplished through various analyses on the data elements that have been identified for the analysis process.

An analysis is performed on a number of specified data items to obtain a measure that will allow part of a hypothesis to be tested. The measure that is obtained is compared against a target value to assess if the system is performing as intended. The outcomes of the analyses will be useful for addressing the experimental components of this project, and ultimately, play a role in determining which system functionalities are ready for implementation. Table 6-13 provides a detailed description of each of the analyses first presented in the Experimental design summary. The analysis description explains how each data item is used to calculate each performance measure.

Table 6-13. Detailed Description of Analysis Procedures

Analysis	Description
Determine if vehicle is in range of mobile device, based on vehicle speed	The mobile device will first receive BSMs from the vehicle containing information about the vehicle's position and speed. Based on the vehicle position (from MEDA Log – BSM) and the mobile device position (from MDEA Log – mobile device GPS data), the distance between the mobile device and the vehicle will be calculated using the Haversine equation.
Analysis of PSMs sent while vehicle is out of range.	Based on vehicle speed (from MDEA Log – BSM), the mobile device will determine the PSM broadcast radius (see Appendix C). If the distance between the mobile device and the vehicle is greater than the PSM broadcast radius, then it should not broadcast PSMs. A log of PSMs sent while the vehicle is out-of-range are counted and divided by the total amount of time the vehicle is out-of-range to assess the PSM Broadcast Rate. PSMs are expected to be broadcast at 0 Hz.
Analysis of PSMs sent while vehicle is in range	If the distance between the mobile device and the vehicle is less than the PSM broadcast radius, then it should broadcast PSMs. A log of PSMs sent while the vehicle is in-range are counted and divided by the total amount of time the vehicle is in-range to assess the PSM Broadcast Rate. PSMs are expected to be broadcast at 10 Hz.
The rate at which PSMs are received by the RSU will be assessed. The mobile	PSM Communication Performance Experiments use a RSU as a "PSM rate meter" to measure PSM signal strength and the fraction

Analysis	Description
device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.	of PSMs received as a mobile device moves away from the RSE. This experiment is based on the understanding that PSMs are “broadcast” without handshake or confirmation of receipt. The experiment is repeated to assess variability is results. As the mobile device moves away from the RSE, a smaller fraction of the total messages sent will be received.
Determine Coordination Status	The MDEA Log records changes in the coordination status, and can be used to determine when the mobile device is in a ‘coordinated’ or ‘uncoordinated’ state.
Analysis of PSMs sent while not part of travel group	If the mobile device is in an ‘uncoordinated’ state, it should broadcast PSMs (if a vehicle is in-range). A log of PSMs sent while uncoordinated are counted and divided by the total amount of time the mobile device is uncoordinated. PSMs are expected to be broadcast at 10Hz.
Analysis of PSMs sent while part of travel group (travel group leader)	If the travel group leader mobile device is in a ‘coordinated’ state, it should broadcast PSMs (if a vehicle is in-range). A log of PSMs sent while coordinated are counted and divided by the total amount of time the mobile device is coordinated. PSMs are expected to be broadcast at 10Hz.
Analysis of PSMs sent while part of travel group (travel group member)	If the travel group member mobile device is in a ‘coordinated’ state, it should not broadcast PSMs (regardless of whether or not a vehicle is in-range). A log of PSMs sent while coordinated are counted and divided by the total amount of time the mobile device is coordinated. PSMs are expected to be broadcast at 0Hz.
Determine that mobile device is not in a vehicle, Determine that mobile device is in a vehicle	The MDEA Log records changes in the in-vehicle status, and can be used to determine when the mobile device is ‘in-vehicle’ or ‘out-of-vehicle’.
Analysis of PSMs sent while not in a vehicle	If the mobile device is ‘out-of-vehicle’, it should broadcast PSMs (if a vehicle is in-range). A log of PSMs sent while out-of-vehicle are counted and divided by the total amount of time the mobile device is out-of-vehicle. PSMs are expected to be broadcast at 10Hz.
Analysis of PSMs sent while in a vehicle	If the mobile device is ‘in-vehicle’, it should not broadcast PSMs (regardless of whether or not a vehicle is in-range). A log of PSMs sent while in-vehicle are counted and divided by the total amount of time the mobile device is in-vehicle. PSMs are expected to be broadcast at 0 Hz.
Based on the speed of the vehicle (in the BSM received by the mobile device), assess the Advisory false alarm rate.	A mobile device will be placed at a known latitude and longitude (in the roadway), recorded in the experimental log. The mobile device broadcasts PSMs containing its location (if a vehicle is in-range). A vehicle approaches the mobile device at a constant speed broadcasting a BSM. The mobile device receives the BSM and records the vehicle’s location, heading, and speed in the MDEA Log. This information, along with the Mobile device’s GPS data, also recorded in the MDEA Log, is used to determine if an advisory, alert, or warning should be issued. The computed issuance of an advisory, alert, or warning is compared against the actual issuance of advisory, alert, and warnings. A contingency table of calculated versus actual issuance is created. The system is assumed to operate properly if it meets operates below a pre-determined false-positive rates and advisories, alerts, and warnings are issued at proper distances. This same analysis is repeated for the issuance of advisories, alerts, and warning in the vehicle - using its GPS information (location, speed, and heading) and PSMs received from the mobile device. It will be of interest to
Based on the speed of the vehicle (in the BSM received by the mobile device), assess the Alert false alarm rate.	
Based on the speed of the vehicle (in the BSM received by the mobile device), assess the Warning false alarm rate.	
Based on the speed of the vehicle (in the BSM received by the mobile device), assess the distance at which an Advisory is issued.	
Based on the speed of the vehicle (in the BSM received by the mobile device), assess the distance at which an Alert is issued.	

Analysis	Description
Based on the speed of the vehicle (in the BSM received by the mobile device), assess the distance at which a warning is issued.	assess the relationship between performance and mobile device positioning accuracy, if experimental data allow.
Based on the speed of the vehicle (in the VEA Log), assess the Advisory false alarm rate.	
Based on the speed of the vehicle (in the VEA Log), assess the Alert false alarm rate.	
Based on the speed of the vehicle (in the VEA Log), assess the Warning false alarm rate.	
Based on the speed of the vehicle (in the VEA Log), assess the distance at which an Advisory is issued.	
Based on the speed of the vehicle (in the VEA Log), assess the distance at which an Alert is issued.	
Based on the speed of the vehicle (in the VEA Log), assess the distance at which a warning is issued.	
Analyze time difference between PSM received and the message display time. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.	When a vehicle receives a PSM from a mobile device, the time the message is recorded in the VEA Log. The time when an advisory/alert/warning is displayed is also recorded in the VEA Log. The difference between when the PSM was received time and the message display time is then calculated. If this calculated message display time is less than a certain latency threshold, the system will be deemed suitable.
Analyze time difference between BSM received and the message display time. The mobile device will be placed in multiple locations on the pedestrian including, in-hand, in-pocket, and in a purse or backpack.	When a mobile device receives a BSM from a vehicle, the time the message is recorded in the MDEA Log. The time when an advisory/alert/warning is displayed is also recorded in the MDEA Log. The difference between when the BSM was received time and the message display time is then calculated. If this calculated message display time is less than a certain latency threshold, the system will be deemed suitable.
Analyze percentage of properly classified safe/unsafe zone detections.	A mobile device will be placed at predesignated safe or unsafe positions, recorded in the experimental log. Once placed at the location, the MDEA Log records raw GPS latitude, longitude, and accuracy data. Using GPS data, the MDEA positions itself in the MAP and determines if it is in a safe or unsafe zone. The mobile device safety status is recorded in the MDEA Log. The mobile device is expected to be exhibit a “Safe” status when placed in a Safe Zone and exhibit an “Unsafe” status when placed in an Unsafe Zone. The percentage of accurate/false zone status determinations will be compared against threshold values to determine if the system is suitable.
Analyze the success rate of receiving a PMM by assessing the events that occur when a PMM is received.	A mobile device sends/receives messages to/from a vehicle to coordinate travel. The sequence of events is expected to be as follows: 1. Mobile device sends PMM to vehicle 2. Vehicle sends PMM-RSP to Mobile Device
Analyze the success rate of receiving a PMM-RSP by assessing the events that occur when a PMM-RSP is received.	

Analysis	Description
Analyze the time between the sending of a mobility request to the receipt of a coordination confirmation	3. Coordination Status of Mobile device changes from “uncoordinated” to “coordinated.” 4. Vehicle sends PMM-ARRIVE to Mobile Device Timestamps on messages sent and received can be used to determine if events happen in the specified order. Furthermore, the contents of each message is recorded to determine if the contents are being properly sent and received.
Analyze the success rate of receiving a PMM-Cancel by assessing the events that occur when a PMM-Cancel is received.	
Analyze the time between the sending of a PMM-cancel message from a mobile device to the receipt of the PMM-Cancel message in the vehicle.	
Analyze the success rate of receiving a PMM-Arrive message.	
Assess false positive rate of transition detection.	
Assess change in “Travel Mode Status” within 10 seconds of pedestrian entering vehicle.	The travel mode status in the MDEA Log indicates a change in travel mode. The observed time the traveler enters the vehicle is recorded in the experimental log. The difference between the observed travel mode change time and the detected travel mode status change time is then calculated. The travel mode status is expected to change within 10 seconds of the traveler entering the vehicle. This experiment is repeated multiple times and is expected to have a 90% success rate.
Assess “Travel Mode Status” false ala before the vehicle has traveled more than 3 meters.	The travel mode status in the MDEA Log indicates a change in travel mode. The observed time the traveler enters the vehicle and the time the vehicle has traveled 3 meters is recorded in the experimental log. The observed travel mode change time is expected to occur prior to the observed time when the vehicle has traveled 3 meters. This experiment is repeated multiple times and is expected to have a 90% success rate.
Determine percentage of Coordination Request messages received by mobile devices when within 10 meters of another coordinating mobile device. Assess message contents for consistency.	A mobile device (1) is placed approximately 10 meters away from a second mobile device (2). Mobile Device 1 will broadcast Coordination Request messages and record when they are sent in the MDEA 1 Log. Coordination Request messages received by Mobile Device 2 will be recorded and timestamped. Coordination Request messages sent from Mobile Device 1 will be matched up against messages received by Mobile Device 2. The difference between the Coordination Request Sent Occurrence logs and the Coordination Request Receipt logs will be calculated in order to determine the accuracy of the system. The message contents will also be monitored in order to ensure consistency. The percentage of messages properly received will be determined by dividing the total number of Coordination request messages received (and properly read) divided by the total number of Coordination Request messages sent. If the percentage of messages received is above a given threshold, then the system is deemed suitable.
Determine percentage of Coordination Request messages properly processed by mobile devices. Determine percentage of Coordination Acceptance messages properly processed by mobile devices.	A mobile device sends/receives messages to/from another mobile device to coordinate travel. The sequence of events is expected to be as follows: 1. Mobile device sends Coordination Request to Mobile Device (Group leader)

Analysis	Description
Determine percentage of Coordination Heartbeat messages properly processed by mobile devices. Determine percentage of Coordination Heartbeat Response messages properly processed by mobile devices. Determine percentage of Coordination Disband messages properly processed by mobile devices.	2. Mobile Device (group leader) sends Coordination Confirmation to Mobile Device 3. Coordination Status of Mobile device changes from “uncoordinated” to “coordinated.” 4. Mobile devices send Coordination Heartbeat messages at pre-defined intervals. 5. Mobile device (group leader) send a Coordination Disband when the vehicle arrives. Timestamps on messages sent and received can be used to determine if events happen in the specified order. Furthermore, the contents of each message is recorded to determine if the contents are being properly sent and received.
Determine percentage of SPaT messages received by mobile devices when within 100 meters of RSE. Assess message contents for consistency.	A mobile device is placed approximately 100 meters away from the RSE. The RSU will broadcast SPaT messages and record when SPaT messages are sent in the RSU Log. SPaT messages received by the mobile device will be recorded and timestamped. Messages sent from the RSU will be matched up against messages received by the mobile device. The difference between the SPaT Sent Occurrence logs and the SPaT Message Receipt logs will be calculated in order to determine the accuracy of the system. The message contents will also be monitored in order to ensure consistency. The percentage of messages properly received will be determined by dividing the total number of SPaT messages received (and properly read) divided by the total number of SPaT messages sent. If the percentage of messages received is above a given threshold, then the system is deemed suitable.
Determine percentage of MAP messages received by mobile devices when within 100 meters of RSE. Assess message contents for consistency.	A mobile device is placed approximately 100 meters away from the RSE. The RSU will broadcast MAP messages and record when MAP messages are sent in the RSU Log. MAP messages received by the mobile device will be recorded and timestamped. Messages sent from the RSU will be matched up against messages received by the mobile device. The difference between the MAP Sent Occurrence logs and the MAP Message Receipt logs will be calculated in order to determine the accuracy of the system. The message contents will also be monitored in order to ensure consistency. The percentage of messages properly received will be determined by dividing the total number of MAP messages received (and properly read), divided by the total number of MAP messages sent. If the percentage of messages received is above a given threshold, then the system is deemed suitable.
Assess percentage of messages received from mobile devices within 100 meters of RSE. Assess message contents to make sure they are consistent.	A mobile device is placed approximately 100 meters away from the RSE. The mobile device will broadcast a variety of safety, mobility, and coordination messages and record when these messages are sent in the MDEA Log. Messages received by the RSU will be recorded and timestamped. Messages sent from the mobile device will be matched up against messages received by the RSE. The difference between the Message Sent Occurrence logs and the Message Receipt logs will be calculated in order to determine the accuracy of the system. The message contents will also be monitored in order to ensure consistency. The percentage of messages properly received will be determined by dividing the total number of messages received (and properly read), divided by the total number of messages sent. If the percentage of messages received is above a given threshold, then the system is deemed suitable.
Assess size of messages and rate at which on-board storage is used.	The stored data size of messages received by the RSU will be determined. The total size of all messages received by the RSU is

Analysis	Description
	calculated and compared to the memory specifications of the RSE. The rate at which on-board storage will be calculated and compared to the maximum storage capacity specifications of the RSU to determine the expected amount of time it will take for the RSU to reach it storage limit.

Source: Battelle

6.5 Risks and Mitigation

Many of the envisioned system functionalities are developed based on the availability of certain system components. However, the ability for these system components to perform at a level required to support the system functionality is not necessarily guaranteed. It is important to make sure the system functions as intended because if it does not, then user needs and expectations will not be met, thereby reducing the impact of the system. Thus, it is important to identify risks that may lead to sub-standard system performance. Once risks are identified, mitigation strategies can be developed to address each risk. Pertaining to the Prototype Proof of Concept Field Demonstration, the greatest risks have been identified below, and described in the following subsections.

- Mobile Device Positioning Uncertainty
- Message Congestion

6.5.1 Mobile Device Positioning Uncertainty

One of the greatest risks toward supporting the safety needs of mobile device users is the positioning ability of the mobile device. It is important to note that the positioning ability of a mobile device (GPS accuracy) will be dependent on the quality of its GPS receiver. The mobile device uses an on-board smartphone GPS antenna to receive location updates once per second. Even under ideal conditions, the mobile device GPS is generally able to provide a position with an accuracy of three (3) to five (5) meters. Accuracy, in reference to GPS positioning, refers to the radius within which a device is able to position itself 68% of the time – which means that about 32% of locations will fall outside of the specified accuracy radius. Most roadway lanes are three (3) to four (4) meters wide, which is somewhat similar to the accuracy of mobile device positioning accuracy.

Assuming the positioning error of a mobile device is normally distributed, the theoretical likelihood of a mobile device detecting its position in a particular region of a MAP can be determined. The following example discusses the lateral positioning distribution of a mobile device on a roadway (where lateral is defined as the direction perpendicular to a vehicle's direction of travel). For instance, a mobile device with an accuracy of 3 meters is placed in the middle of a lane that is 4 meters wide. The likelihood of the mobile device positioning itself at any given time in the lane is about 50%. It will place itself to the left of the lane 25% of the time, and to the right of the lane 25% of the time. An alternative scenario places the mobile device one meter to the right side of the roadway. The likelihood of the mobile device positioning itself at any given time in the lane is about 33%. It will position itself to the right side of the roadway 63% of the time, and on the left side of the roadway 4% of the time.

Based on the assumptions of this the measurements in the scenarios above, the positioning ability of the mobile device does not appear to be accurate enough to support pedestrian safety monitoring applications. While it will be a benefit that the mobile device will provide a location value 10 times per second, the situation increases in complexity once the mobile device begins moving.

Ideally, the system is able to reduce false positive and false negative classifications. Reducing false negative detections can be accomplished by utilizing a safety buffer around the mobile device, effectively increasing the presence of the pedestrian. The safety buffer may vary based on the mobile device reported GPS accuracy (included in the PSM). While adding a safety buffer will reduce the number of false negatives, the tradeoff is an increase in the number of false positive detections – which, in the long run, may result in drivers paying less attention to notifications sent as a result of a detection. The potential implication of false negative detections (not detecting the presence of a pedestrian in the roadway when there a pedestrian is in the roadway) must be weighed against the implications of false positive detections (detecting a pedestrian when there is not a pedestrian in the roadway). Part of the experiment will be to assess the number of false positive and false negative classifications to determine if pedestrian safety monitoring applications can operate within commonly accepted false detection thresholds, as listed in the Performance Measures targets in Table 6-5.

6.5.2 Message Interference and Congestion

Message congestion, though not assessed as part of this project, may present a risk to testing. It is currently unknown how many messages will need to be sent in order to have an impact on the message-receiving capability of a DSRC radio antenna. Channel congestion and message interference may result in applications not working as intended.

Although messages congestion will not be tested, the following discussion will provide a basis for the development for channel congestion tests on future projects. To assess message congestion performance, a sufficient number of messages must be sent from multiple devices such that a receiving device is not able to properly parse messages, interpret messages, and take action based on messages in a sufficient amount of time. The term “sufficient number” has not been tested or defined, because connected vehicles typically have more than sufficient communication range to support safety and mobility applications, unless there is a physical obstacle. It is not known at this time if Mobile Devices have sufficient communication range to support the most challenging applications. A congestion control algorithm could be applied to PSMs (similar to the congestion control algorithm specified in J2945-1 for BSMs) to improve performance. Furthermore, a channelization approach (specifying which messages are sent over which channel) could be developed to reduce the likelihood of channel congestion – channelization approaches commonly broadcast safety and mobility messages over different channels.

6.6 Turner-Fairbank Highway Research Center Field Demonstrations

The demonstrations and tests listed in Table 6-14 have been proposed to test each of the hypotheses developed earlier in this section. The hypotheses that each test supports is listed next to the test in the table. This also provides traceability from the tests back to the hypotheses. Test procedures, expected results, and measurements/verification methods will be elaborated upon in the Task 6 System Acceptance Plan.

Table 6-14. System Acceptance Tests

Demonstration/Test	Hypotheses Supported
Taxi Travel Request, Coordination Message, and Travel Mode Detection Experiments	
Uncoordinated Travel	2
Coordinated Travel (Mobility messages via DSRC)	
Formation of New Travel group	8
Traveler Joins Travel Group	2, 13
Traveler Leaves Travel Group	13
Pedestrian-to-Taxi Detection	3, 10, 11
Taxi-to-Pedestrian Detection	11
Coordination Attempt – Variation: Trip Details do not Match	13
Coordination Attempt – Variation: Heartbeat Message not Received	13
Transit Travel Request, Coordination Message, and Travel Mode Detection Experiments	
Coordinated Travel (Mobility messages via Cellular)	
Formation of New Travel group	9
Traveler Joins Travel Group	2, 13
Traveler Leaves Travel Group	13
Pedestrian-to-Transit Bus Detection	3, 10, 12
Transit bus-to-Pedestrian Detection	12
PSM Communication Performance Experiments	
PSM Reception Rate (mobile device in various locations)	4
Pedestrian Collision Monitoring Application Performance Experiments	
Alert/Advisory/Warning Reception Accuracy (stationary mobile device, moving vehicle)	1, 5, 6
Alert/Advisory/Warning Reception Accuracy (moving mobile device, moving vehicle)	1, 5, 6
RSE Message Broadcast/Receive Experiments	
Mobile Device SPaT Reception Rate (mobile device in various locations)	14
Mobile Device MAP Reception Rate (mobile device in various locations)	14
RSE Reception Rate (various messages from multiple sources)	15
Mobile Device Positioning Experiment	
Save/Unsafe Zone Location Detection	7

Source: Battelle

6.7 Future Tests Experiments

Results of the Prototype Proof of Concept Field Demonstration will be used to determine if the hypotheses are being met. The hypotheses are developed to assess whether or not the developed system is functioning as intended and is accomplishing the objectives of the project.

Several concepts for the use of mobile devices to support connected vehicle applications were presented in the Concept of Operations. However, the utility of mobile devices in the connected vehicle space is largely untested, and it is unknown if mobile devices are able to support all of the functional concepts they are intended to support. The evaluation assesses the readiness of various components the system. Results of analyses presented in the evaluation plan will be used to determine which system functionalities can be used in deployment, and which require further technological advancement before deployment is feasible.

The Prototype Field Demonstration for this project includes implementation of the system in a live environment. Functionalities included in the Prototype Field Demonstration system need to pass a thorough evaluation process. Proper operation in the live environment is crucial for maintaining the user's expectation of safety and mobility. Gaining an understanding of if the system meets user safety and mobility expectations is one of the primary purposes for conducting the Prototype Proof of Concept Field Demonstration. Functionalities tested in the Prototype Proof of Concept Field Demonstration that meet acceptance criteria will be included in the system deployed in the Prototype Field Demonstration, while functionalities that do not meet acceptance criteria will not. In summary, the Prototype Field Demonstration system will include a properly-working subset of the functionalities included in the Prototype Proof of Concept Field Demonstration system.

APPENDIX A. ACRONYMS AND ABBREVIATIONS

Acronym	Description / Explanation
3GPP	3rd Generation Partnership Project
ADA	Americans with Disabilities Act
AERIS	Applications for the Environment: Real-Time Synthesis Program
Android	Google-based Operating System
APC	Automatic Passenger Counts
API	Application Program Interface
APS	Accessible Pedestrian Signal
ASC	Actuated Traffic Signal Controller
ATDM	Active Transportation and Demand Management
ATIS	Advanced Traveler Information System
ATTRI	Accessible Transportation Technologies Research Initiative
AVAS	Automatic Voice Annunciation System
AVL	Automatic Vehicle Location
BLE	Bluetooth Low Energy
BSM	Basic Safety Message
CAD	Computer-Aided Dispatch
CAM	Cooperative Awareness Message
CAN	Controller-Area Network
CDMA	Code Division Multiple Access
ConOps	Concept of Operations
CSW	Curve Speed Warning
CVRIA	Connected Vehicle Reference Implementation Architecture
D-RIDE	Dynamic Ridesharing
DCM	Data Capture and Management
DENM	Decentralized Environmental Notification Message
DMA	Dynamic Mobility Applications Program
DMS	Dynamic Message Signs
DSRC	Dedicated Short Range Communications

Acronym	Description / Explanation
DVI	Driver-Vehicle Interface
EDGE	Enhanced Data Rates for GSM Evolution
EEBL	Emergency Electronic Brake Light Application
EnableATIS	Enabling Advanced Traveler Information System
EPS	Experimental Prototype System
ETA	Estimated Time of Arrival
ETSI	European Telecommunications Standards Institute
EVAC	Emergency Communications and Evacuation
FHWA	Federal Highway Administration
FCW	Forward Collision Warning
FTA	Federal Transit Administration
GIS	Geographic Information System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Telecommunications
GTM	Government Task Manager
HDOP	Horizontal Dilution of Precision
HSPA	High Speed Packet Access
HSPA+	Evolved High-Speed Packet Access (HSPA+)
I2V	Infrastructure-to-Vehicle
IEEE	Institute of Electrical and Electronics Engineers
INC-ZONE	Incident Scene Work Zone Alerts for Driver and Workers
IDTO	Integrated Dynamic Transit Operations
iOS	Apple iPhone Operating System
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
LAN	Local Area Network
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
LTE	Long-Term Evolution
MAC	Medium Access Control
MAW	Motorists Advisories and Warnings
MIMO	Multiple Input, Multiple Output
MSAA	Mobility Services for All Americans
NDEF	NFC Data Exchange Format

Acronym	Description / Explanation
NFC	Near Field Communication
NFCIP	Near Field Communication Interface and Protocol
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
OS	Operating System
OSU	Ohio State University
PCW	Pedestrian in Signalized Crosswalk Warning Application
PED-SIG	Mobile Accessible Pedestrian Signal Systems
PHY	Physical Layer
PDOP	Position Dilution of Precision
PMM	Personal Mobility Message
PSM	Personal Safety Message
R.E.S.C.U.M.E	Response, Emergency Staging, Communications, Uniform Management, and Evacuation
RFID	Radio Frequency Identification
RESP-STG	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SDK	Software Development Kit
SET-IT	Systems Engineering Tool for Intelligent Transportation
SPaT	Signal Phasing and Timing
SSID	Service Set Identifier
SysReqs	System Requirements
TCP/IP	Transmission Control Protocol/Internet Protocol
T-DISP	Dynamic Transit Operations
TOC	Transportation Operation Center
TRP	Transit Retrofit Package
UMTS (WCDMA)	Universal Mobile Telecommunications System (Wideband Code Division Multiple Access)
U.S. DOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDOP	Vertical Dilution of Precision
VDT	Vehicle Data Translator
VSL	Variable Speed Limit

Acronym	Description / Explanation
VSM	Vehicle Situation Data Message
VTRW	Vehicle Turning Right in Front of Bus Warning
WAVE	Wireless Access in Vehicular Environments
Wi-Fi	Wireless Fidelity
WxTINFO	Weather Responsive Traffic Information
XML	Extensible Markup Language

Source: Battelle

APPENDIX B. TERMS AND DEFINITIONS

Term	Definition
Accelerometer	Hardware sensor that measures the acceleration force on the device along three axes.
Android	Google's operating system. Naming convention incorporates sweets (i.e., éclair, donut)
Barometer	Hardware sensor that measures the pressure of air surrounding the device.
Basic Safety Message (BSM)	Connected vehicle message type which contains vehicle safety-related information that is broadcast to surrounding vehicles;
Bluetooth	Short range wireless technology used to exchange data between enabled devices
Coordinated	Messages are coordinated when one or more mobile devices have boarded a single vehicle (i.e. multiple passengers have boarded a bus), and are interpreted as a single, cohesive sender/recipient.
Destination	The end point of a traveler's trip.
DSRC	Dedicated Short-Range Communications; a low-latency, high-reliability, two-way communications tool used for sending transportation safety messages.
Emergency Vehicle Alert Message	Connected vehicle message type which is used to communicate warnings to surrounding vehicles that an emergency vehicle is operating within the vicinity;
Fragmentation	Occurrence in which mobile device users are operating on different versions/releases of a device's operating system.
Gravity (Sensor)	Software sensor that estimates the force of gravity along the three axes.
Gyroscope	Hardware sensor that measures the rate of rotation of the device along three axes.
Hygrometer	Hardware sensor that measures the humidity of the air surrounding the device.
Light Sensor	Hardware sensor that measures ambient light.
Linear Acceleration	Software sensor that estimates the acceleration force of the device along three axes, excluding gravity.
Link	A trip chain phase in which the traveler is in transit.
Magnetometer	Hardware sensor that measures the geomagnetic field surrounding the device along 3 axes.

Term	Definition
Message Type	Type of personal safety or personal mobility message that is transmitted based on the technology used and level of coordination available.
Mobile Hardware Sensor	Reports raw data from a particular sensor on the mobile device
Mobile Network	A wireless radio network distributed over a large geographic area with fixed location transceivers spread across it. These receivers work together to provide radio coverage over the entirety of the geographic area allowing a large number of mobile devices to communicate with each other.
Mobile Software Sensor	Interprets data from one or more hardware sensors to provide an imputed output
National ITS Architecture	Common framework for the planning, development and integration of ITS deployments.
NFC	Near Field Communications; short-range communications technology (typically 1-2 inches) that may be used to make payments via mobile devices.
Node	A trip chain phase in which the traveler is located at a transition point, such as a bus stop or train station.
Not Transmitting	The state in which a mobile phone user has not opted in to exchanging safety and mobility messages
Operating System	The prerequisite mobile device software (e.g. Android, iOS, etc.) that manages all other applications.
Opt-In	User action required to begin transmission of safety and mobility messages via mobile device.
Opt-Out	User action required to end transmission of safety and mobility messages via mobile device.
Origin	The starting point of a traveler's trip.
Personal Mobility Message (PMM)	Similar to PDM, message intended for the exchange of mobility messages between individual travelers and vehicles/infrastructure, via mobile device.
Personal Safety Message (PSM)	Similar to BSM, message intended to transmit low-latency, urgent safety messages between individual travelers and vehicles/infrastructure, via mobile device
Proximity	Hardware sensor that measures the distance between the sensor and a nearby object.
Road Condition Message	Connected vehicle message type which provides information on roadway surface conditions, such as the presence of ice
Rotation Vector	Software sensor that describes the orientation of the screen of a mobile device.
Step Detector/ Counter	Software sensor that uses accelerometer data to estimate when a step has been taken.
System Engineering Tool for Intelligent Transportation (SET-IT)	A single software tool that integrates drawing and database tools with the Regional Unified Model Architecture so that users can develop project architectures for pilots, test beds and early deployments.
Thermometer	Hardware sensor that measures he temperature of air surrounding the device.

Term	Definition
Transmitting	The state in which a traveler has opted in and is sending/receiving messages via mobile device
Traveler advisory message	Connected vehicle message type which Provides congestion, travel time, and signage information.
Trip Chain	A term used to describe the duration of a trip from origin to destination, including all nodes and links that a traveler encounters.
Trip Chain Phase	A duration of a trip chain in which a traveler is either at a node or traveling within a link. A phase can only include a node or a link, not both.
Uncoordinated	Messages are coordinated when one or more mobile devices have boarded a single vehicle (i.e. multiple passengers have boarded a bus), and are interpreted as a single, cohesive sender/recipient.
Weather Condition Message	Connected vehicle message type which communicates area specific weather information
Wi-Fi	Local area wireless technology that allows enabled devices to connect to the Internet

Source: Battelle

APPENDIX C. MESSAGE DISPLAY EQUATIONS

The fundamental requirement for pedestrian safety applications is that the driver must be warned of the potential for imminent collision in time to safely stop the vehicle without striking into the pedestrian.

It follows then that the distance at which advisories, alerts, and warnings must be greater than the vehicle stopping distance in order for the connected vehicle equipment to receive the PSM, process it, determine that a collision is imminent and issue a warning to the driver. Stopping distance equations are functions of distance from the vehicle to the pedestrian, vehicle speed, and vehicle deceleration capability. These variables are defined below, followed by an explanation of the equations themselves. The stopping distance can be described in text form as:

$$\begin{aligned} Stopping\ Distacne \\ &= Safety\ Factor \\ &* \{(Communications\ and\ Computational\ Latency\ time \\ &+\ Driver\ Perception\ Reaction\ Time) * velocity\} + \left\{\frac{velocity^2}{2 * deceleration}\right\} \end{aligned}$$

This expression can be written in mathematical terms as

$$d = SF * \left\{[(CCL + PRT) * v] + \frac{v^2}{2a}\right\}$$

where

- d is the stopping distance (meters)
- CCL is communications and computational latency time (seconds) (assumed equal to 0.5 seconds)
- PRT is driver Perception Reaction Time (seconds) (assumed equal to 2.5 seconds)[14]
- v is vehicle initial speed (meters/second)
- a is vehicle acceleration rate, negative for deceleration to stop (m/sec^2).
- SF is the safety factor (assumed to be 1.1)

Various factors could impact specific variables used in calculating the above equations. For example, changing weather or road conditions and vehicle-specific operating characteristics can change the values used for the above equations. Lower friction due to road surface conditions or vehicle tire wear could increase the safe distances and safe deceleration rates. The vehicle type and operating characteristics could also impact when vehicle-specific alerts and warnings that are issued. Some of these variables are discussed below.

[14] National Cooperative Highway Research Program (NCHRP) Report 600. Human Factors Guidelines for Road Systems, 2nd edition. 2012.

Perception Response Time. Perception-response time or perception-reaction time (PRT) is generally accepted to be 2.5 seconds by the MUTCD and AASHTO.[15] This time must be considered to account for the time and distance that the vehicle travels at the initial speed from the time the driver receives the message before reacting to it, and added to the value of time or distance needed for a car to decelerate to a stop or reduced speed. The AASHTO "Policy on Geometric Design of Highways and Streets" does suggest that 2.5 seconds may not be adequate for the more complex conditions encountered in driving

Acceleration. The selected acceleration rates used for calculating alert and warning distances, specifically for decelerating to a reduced speed or a complete stop, could vary based on many factors. Some of these factors may not be required by the application and use default or assumed values if unavailable, such as the road surface friction or weather information. Other factors are static for each given deployment, such as the grade of the roadway. Still other factors vary at each deployment for each individual vehicle, such as the vehicle operating characteristics like the braking capabilities.

NCHRP Report 400[16] indicates that most drivers decelerate at a rate that is greater than 18.4 ft./s^2 (5.6 m/s^2) when there is a sudden need to stop for an unexpected object in the roadway, while design braking rates are 11.2 ft./s^2 (3.4 m/s^2). These deceleration rates account for the comfort level of drivers, the ability of the driver to maintain steering control on wet surfaces in tandem with tire-pavement friction levels, and vehicle braking systems capabilities.

The deceleration rate could actually be configured to reflect a vehicle's breaking capability, but for the purposes of this project, constant values will be used.

Advisory, Alert, and Warning Distances

An advisory is issued when there are pedestrians in the vicinity of the vehicle. J2945-9 6.3.3 specifies that a mobile device only issues PSMs when the mobile device determines that it is in the presence of a vehicle. The distance at which a mobile device broadcasts PSMs provides approximately 9 seconds (constant) vehicle travel time to the traveler's location. An advisory will be displayed to the driver when the driver is at a distance that is 9 seconds from a pedestrian at its given speed. Because a mobile device will only broadcast PSMs when the vehicle is less than 9 seconds away, an advisory will be displayed to a driver when a PSM is received. The display distance equation for advisory messages is displayed below:

$$d_{Advisory} = v * 9$$

Where

- $d_{Advisory}$ is the advisory display distance (meters)
- v is the velocity of the vehicle (meters per second)

[15] Policy on Geometric Design of Highways and Streets (6th Edition), 2001, AASHTO

[16] Fambro, D.B, K Fitzpatrick, and R.J. Koppa, "Determination of Stopping Sight Distance," NCHRP Report 400, TRB, Washington, DC, 1997. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_400.pdf

In keeping with the distance-based standard for displaying an advisory, distances will also be used to determine when an alert or warning are issued. Unlike the distance at which an alert is issued, the distance at which an alert or warning should be based on the distance it takes to stop a vehicle at a given speed. The stopping distance equations and assumptions developed above must be used. An advisory will be issued to the driver when they must apply the brakes at a typical pressure to avoid a potential impending collision with a pedestrian. A warning will be issued to a driver when the driver must apply the maximum braking power to avoid the potential impending collision. The display distance equations for alert and warning messages is displayed below:

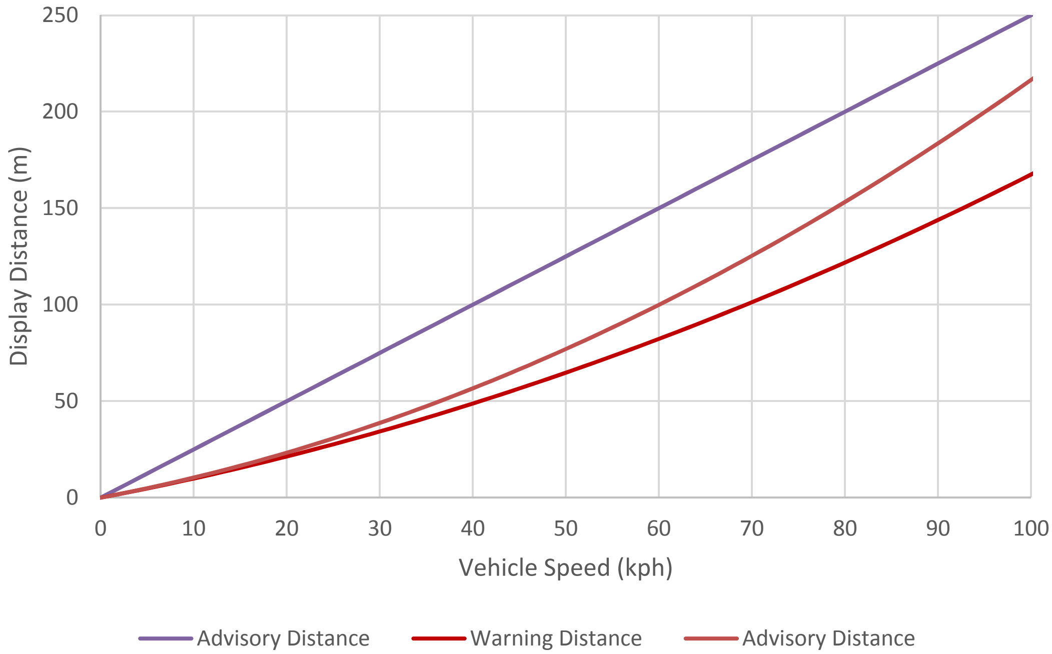
$$d_{alert} = 1.1 * \left\{[(0.5 + 2.5) * v] + \frac{v^2}{2(3.4)}\right\}$$

$$d_{warning} = 1.1 * \left\{[(0.5 + 2.5) * v] + \frac{v^2}{2(5.6)}\right\}$$

Where

- d_{alert} is the alert display distance (meters)
- $d_{warning}$ is the warning display distance (meters)
- v is the velocity of the vehicle (meters per second)

Figure C-1 provides a plot of alert, advisory, and warning display distances as a function of vehicle speed for an automobile, based upon the assumptions outlined above. These suggestions need to be tested and evaluated from both human factors and actual vehicle braking performance perspectives.



Source: Battelle

Figure C-1. Message Display Distance

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