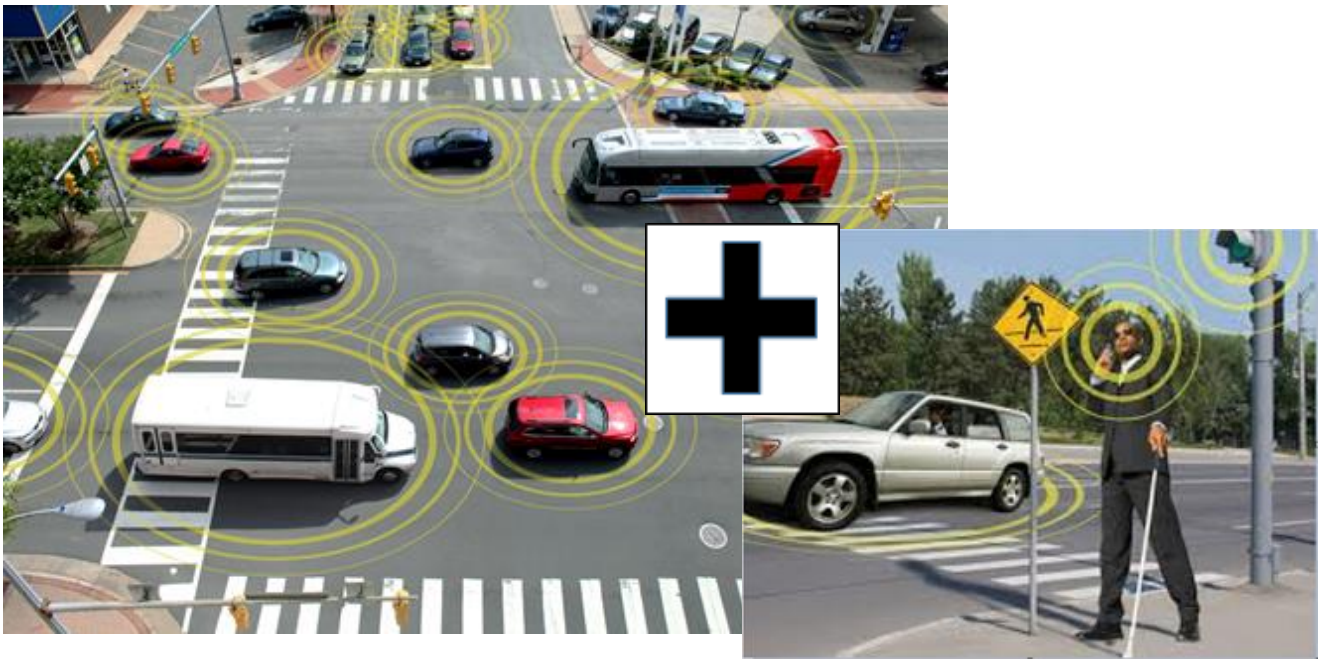
Sharing Data Between Mobile Devices, Connected Vehicles, and Infrastructure

Task 3: System Requirements Specifications (SyRS)

FINAL

www.its.dot.gov/index.htm
Report — July 14, 2016
FHWA-JPO-16-423



U.S. Department of Transportation
Federal Highway Administration

Produced by Battelle Memorial Institute under DTFH61-12-D-00046
U.S. Department of Transportation
FHWA Office of Operations Research and Development

Picture Sources: U.S. DOT Office of the Assistance Secretary for Research and Technology, Intelligent Transportation Systems, Joint Program Office

Notice

Quality Assurance Statement

The Federal Highway Administration provides high quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-16-423		

4. Title and Subtitle	5. Report Date
Task 3: System Requirements Specifications (SyRS)	July 14, 2016
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Thomas Timcho, Denny Stephens (PhD), Christopher Toth (PhD), Matt Burns, Joerg 'Nu' Rosenbohm	100053418-302

9. Performing Organization Name And Address	10. Work Unit No. (TRAIS)
Battelle 505 King Avenue Columbus, OH 43201	11. Contract or Grant No. DTFH61-12-D-00046 / 5015

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation FHWA Office of Operations Research and Development Turner-Fairbank Highway Research Center 6300 Georgetown Pike McLean, VA 22101	14. Sponsoring Agency Code

15. Supplementary Notes

Government Task Monitor – Jon Obenberger

16. Abstract

This report describes the system requirements specifications (SyRS) for the use of mobile devices in a connected vehicle environment. Specifically, it defines the different types of requirements (functional, interface, performance, security, data, and reliability requirements) addressing the identified needs, conceptual system, and potential scenarios from the Task 3: Concept of Operations report. The SyRS serves as the basis for development of the experiment prototype system that will be used to demonstrate both safety and mobility benefits of using mobile devices including how the interactions and messaging of these devices may be coordinated in order to provide more efficient (and less congested exchange of information) and how these devices might behave in an environment where mobile device coordination does not exist.

17. Key Words	18. Distribution Statement
Mobile Device Message Coordination Prototype, Connected Vehicle, Mobile Device, Coordinated Mobile Device, Personal Mobility Message, Personal Safety Message, Connected Person Fleet, SyRS, system requirements specifications	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	87	N/A

REVISION HISTORY

Revision	Date	Change Description	Affected Sections/Pages
-	12/29/2015	Initial Release	
	3/29/2016	2nd Draft SysRS based on 2nd Revised Draft of the Concept of Operations, which was re-opened and modified based on GTM request	Most sections
	5/19	Final SysRS (review version)	Addressing comments by USDOT
	7/14	Final SysRS	Addressing final comments by USDOT

Table of Contents

List of Tables

List of Figures

Chapter 1 Scope

The purpose and vision of this experimental research project is to enable the support in exchanging messages with mobile devices within the public right of way, to enhance the safety and mobility of these trips, and to enable the public agencies to improve how they manage traffic, which includes travelers using mobile devices.

This document contains the functional, performance, interface, security, data and reliability requirements associated with the experimental prototype system to be developed as part of the "Coordination of Mobile Devices for Connected Vehicle Applications" project. This document has been written with the assumption that the reader possesses a general knowledge associated with the connected vehicle technologies and applications and the systems engineering process.

This document was developed based on the contents of the 2nd Revision of the Concept of Operations (ConOps / dated March 2016), specifically the User Needs identified in that document. The ConOps-defined scenarios were the basis for the User Needs. But it needs to be noted that the User Needs were developed to address fundamental research questions associated with mobile devices in the connected vehicle environment and the principles of the scenarios (and not to fulfill the exact scenario definitions). For example, Scenario 3 states that the mobile device user in a wheelchair requests a ride with a paratransit vehicle from his house. The corresponding user needs would simply state that the user needs to be able to send a travel / ride request message (UN 4.01) regardless of the location of the user or whether the user is in a wheelchair, which would be part of the ride-request message. Additionally, not all steps defined within one of the scenarios are mapable to a specific User Needs, but instead are addressed by one or more user need.

The ConOps and SysRS-defined user needs and system requirements have been developed to address end-to-end trips performed by mobile device users including transmitting request information prior to performing a trip, information exchanges during trips including walking to / from vehicle-based pick-up locations, interacting with responding vehicles (DSRC-equipped and non-DSRC-equipped transit and ride-sharing vehicles as well as with other DSRC-equipped vehicles), interacting with other travelers while on the trip, potentially serving as a surrogate Basic Safety Message transmitter while in non-DSRC-equipped vehicles, and transceiving information from roadside devices. However, to keep the complexities of what can be accomplished in a limited software development and demonstration effort while at the same time ensuring that the overall purpose of determining data transmission congestion is maintained, the data exchanges are being tracked but not all received data is being acted upon.

1.1 Background

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. And while originally conceived as an enabler for the mobility-impaired and other travelers with unique needs when the concept of the connected vehicle environment first emerged, 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 congestion 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. The project is focused on the development of the capability to support the end-to-end testing of the exchange of messages for a traveler using a mobile device as the complete their trip within the public right-of-way. The design and development of this project is expected to cover several phases. The design of the initial project (the experimental prototype software) will focus on the project objectives, while the design of the initial prototype will support the expansion in subsequent phases of the project that is needed to enable the ultimate capability.

1.2 Terminology

The meanings of the auxiliary verbs used in this document are defined as follows:

- Shall — Compliance with a requirement, specification or a test is mandatory
- Should — Compliance with a requirement, specification, or a test is recommended
- May — Expresses a permissible way to achieve compliance

1.3 Identification

This document is one of the deliverables for Task 3 of Coordination of Mobile Devices for Connected Vehicle Applications, which is being conducted by Battelle Memorial Institute for the Federal Highway Administration (FHWA) under Contract Number DTFH61-12-D-00046 / 5015. This document is the deliverable System Requirements Specification (SyRS). This document defines the functional, system interface, performance, security, data, and reliability requirements associated with this

experimental prototype system, which are addressing the needs determined within the concept of operations (Deliverable 1 of this Task 3).

1.4 Document Overview

The purpose of this document is to further elaborate on the concepts and scenarios described in the re-opened and modified Concept of Operations (ConOps) report. This will be accomplished by describing how the system is to operate in terms of detailed requirement statements.

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 (System Requirements) includes:
  - an overview of the system of interest
  - the system constraints and assumptions
  - the different types of systems requirements (functional, performance, etc.)
  - the User Needs to Requirements Traceability Matrix
- Appendix A contains the Acronyms and Abbreviations
- Appendix B contains the Terms and Definitions

1.5 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 Applicable 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

Institute of Electrical and Electronics Engineers (IEEE)

IEEE 1233-1998	IEEE Guide for Developing System Requirements Specifications
IEEE 1609.x	IEEE Family of Standards for Wireless Access in Vehicular Environments (WAVE) define an architecture and a complementary, standardized set of services and interfaces that collectively enable secure vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications.

Society of Automotive Engineers (SAE)

J2735:2016	Object Dedicated Short Range Communications (DSRC) Message Set Dictionary – published
J2945/1 - draft	On-Board System Requirements for V2V Safety Communications
J2945/2 - draft	DSRC Requirements for V2V Safety Awareness
J2945/6 - draft	Performance Requirements for Cooperative Adaptive Cruise Control and Platooning
J2945.9 - draft	Performance Requirements for Safety Communications to Vulnerable Road Users

National Transportation Communications for ITS Protocol (NTCIP)

1093:2009 V01.27	Transportation Management Protocols
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.

Wi-Fi Alliance

Wi-Fi Peer-to-Peer Services Technical Specification Package v1.2
See (http://www.wi-fi.org/discover-wi-fi/wi-fi-direct) for more

Battelle Memorial Institute

FHWA-JPO-15-TBD	Concept of Operations Document for Coordination of Mobile Devices for Connected Vehicle Applications (Revised draft from July 16, 2015)
FHWA-JPO-16-TBD	Concept of Operations Document for Coordination of Mobile Devices for Connected Vehicle Applications (Final draft from May 18, 2016)

2.2 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 System Requirements

3.1 General

Well-formed requirements, in conjunction with a properly identified concept of operations including the needs of the users, are the basis for the successful design and creation of any system. Well-formed requirements must follow a specific format and include:

[Actor] [Action] [Target] [Constraint] [Localization]

Where:

- Actor Identifies who or what that does the action
- Action Identifies what is to happen
- Target Identifies who or what receives the action
- Constraint Identifies how to measure success or failure of the requirement
- Localization Identifies the circumstances under which the requirement applies

Note that localization and constraint portions are important but not all requirements will have both.

The characteristics of well-formed requirements are:

- Necessary – requirements must be useful and traceable to needs.
- Concise – requirements should be expressed in the minimum number of words, be understandable, and be expressed in a declarative language (i.e., "shall" statements).
- Attainable – requirements must be realistic to achieve within available resources and time.
- Standalone – a requirement must be stated completely in one place, and must not be grouped with other requirements
- Consistent – a requirement must not contradict itself, nor can it contradict any other stated requirement
- Unambiguous – a requirement must be stated in a manner so that there is only one interpretation
- Verifiable – a requirement must be written with testing in mind, i.e., only statements that allows to determine whether the requirement has been met through one of four possible methods: inspection, analysis, demonstration, or test.

3.2 System Description

The experimental prototype system (EPS) for the Coordination of Mobile Devices in Connected Vehicle Applications project centers on potentially expanding the current connected vehicle environment by providing for coordinated mobile devices that include several new types of messages; a Personal Safety Message (PSM), a Personal Mobility Message (PMM), coordination messages, and Surrogate BSMs which are further described in the next paragraphs.

1. The PSM is expected to be patterned after the PSM defined in the new 2016-version of the SAE J2735 standard. The J2735-defined PSM transmits a mobile device's position, speed, and heading, among other information. For a general collision avoidance application, surrounding vehicles could receive the PSM, and along with its own telematics, determine if a collision is imminent. If a Map Data (MAP) message is available, a vehicle can use the PSM to determine the location of a pedestrian within the context of the roadway; – for example, a pedestrian in a crosswalk or a runner in the street. New applications could be written for the vehicle platforms so their drivers are aware of foot traffic. This may have benefits, for example, at roundabouts, where drivers must look for targets in many locations. It also has,

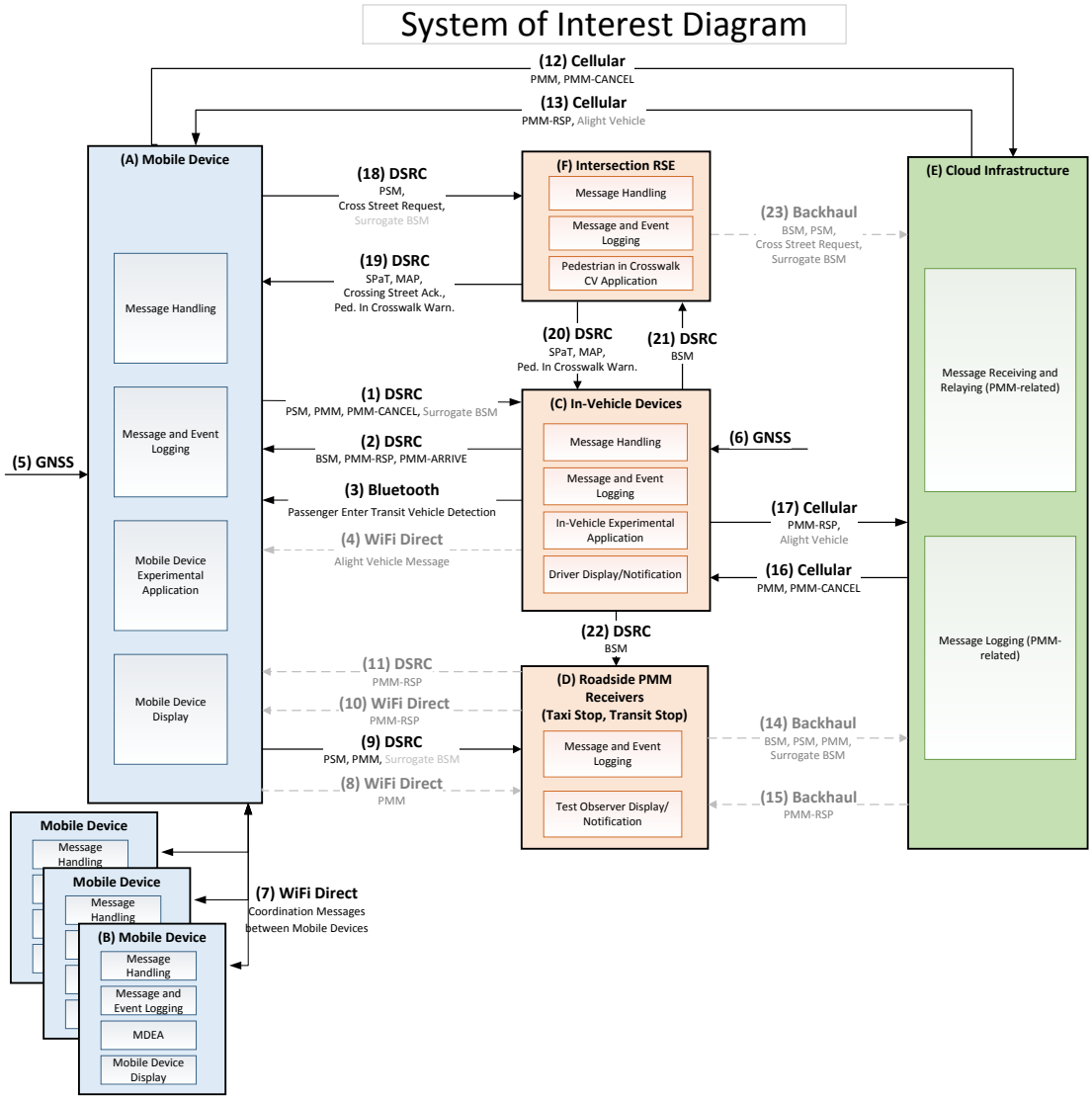
for instance, the potential to reduce injuries in situations where drivers look left while they turn right on red.

2. The PMM will enable new applications benefitting a variety of users. It is expected to contain information about the traveler's next intended movement (i.e. the next portion of a traveler's trip that is expected to take place on a single mode or within a single system where availability/capacity for transport could be limited, e.g. shared bicycle/car, transit/taxi, etc.) to get from departure location to destination location and their requirements for travel such as schedule constraints, mobility issues, etc. The PMM will also contain information about the constraints on the traveler's trip such as requiring a transit vehicle with a wheelchair lift. Other messages that support the mobility applications of the PMM include the PMM-RSP, PMM-ARRIVE, and PMM-CANCEL messages. The PMM-RSP is a message sent from a vehicle back to a travel group leader to acknowledge that the travel group can be accommodated. The vehicle sends a PMM-ARRIVE message to let the group leader know that the vehicle is in the vicinity for the purposes of disbanding the group, and that they will soon enter the vehicle. A PMM-CANCEL message is issued from a mobile device back to a vehicle if a travel group completely dissolves before the vehicle arrives, or if the travel group leader receives more than one PMM-RSP from a vehicle.
3. Coordination messages will allow mobile devices to directly and efficiently communicate with each other at a "local level" for the purpose of reducing the overall communication burden of the communications system in terms of the throughput mainly on DSRC radio links. In particular, these coordination messages will be used to temporarily "link" travelers together into ad-hoc travel groups so that only a single message representing the group needs to be transmitted to an infrastructure component or vehicle component rather than individual messages from every member of the group.
4. A surrogate BSM is a BSM-like message transmitted by a mobile device, if the mobile device detects that it is in a vehicle not equipped with the capability to broadcast BSMs. Surrogate BSMs cannot contain all the information contained in a BSM, because a mobile device will not know what type of vehicle it is in or be able to access information available to the vehicle's telematics. Note that surrogate BSMs are defined for research purposes, but are not implemented in any of the prototype systems associated with this project.

The proposed system will be utilized in a small-scale demonstration to understand and to test different communication mechanisms, message content, message timing, etc. That is, the proposed system will be used in a controlled test environment. Following successful completion of the small-scale demonstration, the proposed system will be used in a naturalistic setting with recruited real-world travelers. These systems will be used in as a "demonstration" and will not impact operations of the transit vehicles, light duty vehicles, or travelers.

A logical "system of interest" diagram of the EPS is shown in Source: Battelle

Figure 1.



Note: Communications in gray will not be included in the EPS.

Source: Battelle

Figure 1. Experimental Prototype System (EPS) 'System of Interest' Diagram

The EPS "system of interest" diagram shows the different components performing certain functions and the communications interfaces between the components including the desired communications media and the data exchange contents. Within the diagram, a main instance of the Mobile Device (see (A) within the diagram) is shown in the upper left, complete with all interfaces to/from the other major functional components. A second 'group' of these same functionally-equivalent mobile devices (see (B) in the diagram) is shown in the lower left and represent the additional devices that interact in the system to create the 'coordinated' travel groups (see (7) within the diagram). The mobile devices in this group receive Global Navigation Satellite System (GNSS) inputs (see (5) in the diagram) and exchange similar data over the same communications interfaces as the representative device. The

GNSS provides information such as latitude, longitude, speed, and heading. Additionally, the diagram uses logical symbols even if some have physical attributes.

The entire EPS centers around the mobile devices and their interaction with each other as well as with other components such as vehicles, roadside receivers, and cloud infrastructure.
Vehicles (see (C) in the diagram) include 'equipped' vehicles, meaning those vehicles that support DSRC communications and, as a minimum, BSM message broadcasting, and 'unequipped' vehicles meaning those vehicles that do not have the capability to generate BSM messages and to send messages over DSRC communications. Vehicles will also receive GNSS data (see (5) in the diagram) to determine their location.

Light duty vehicles and transit vehicles are used within the EPS. These vehicle types have been chosen because they have different mobility-providing capabilities, different capacities, and are expected to provide different scenarios for testing sensor-based passenger detection.

1. Light duty vehicles (passenger vehicles) representing vehicles, such as taxis and ride-sharing vehicles, are capable of picking up and dropping off one or more passengers at random as well as defined pick-up and drop-off points along a roadway. Light-duty vehicles have a capacity of three passengers and cannot cater to the mobility needs of wheelchair users. They have multiple doors from which travelers may enter the vehicle to take their seat.
2. Transit vehicles representing larger-body vehicles are capable of picking up and dropping off several passengers with or without special equipment for special needs passengers, such as wheelchair-bound passengers, at defined pick-up and drop-off locations. A transit vehicle typically has a large passenger capacity and is able to accommodate a limited number of wheelchair users. Travelers enter the transit vehicle from one location and must typically walk to their seat.

The purpose of the roadside receivers (see (D) in the diagram) is not operational but to capture all DSRC-based message exchanges from and to mobile devices including timestamps of messages sent and received, message types (BSM, PMM, PSM, Cross Street Request, etc.), and message contents. The roadside receivers will be equipped to receive all messages sent over DSRC communications within the capture range (see (7) in the diagram). The roadside receivers in the EPS do not provide/add any functionality to the system. They are for EPS communications monitoring only.

The purpose of the cloud infrastructure (see (E) in the diagram) is for relaying travel requests to a vehicle capable of transporting passengers (see (12), (13), (16) and (17) in the diagram). The function of the cloud infrastructure is to enable sending and receiving messages over cellular communications media, as well as to capture all message exchanges between mobile devices and devices within vehicles capable of receiving and sending cellular communications. Messages received by an RSE that is connected to the cloud could also be sent to the cloud infrastructure, although this functionality will not be tested in the EPS. The data captured by the cloud infrastructure include timestamps of messages sent and received, message types (within the EPS this is limited to PMMs), and message content. A TMC or other traffic management agency would be able to access and process this message data to manage demand of the various networks with the tools and management strategies at their disposal.

The purpose of the Intersection RSE (see (F) in the diagram) is twofold:

1. Serve as a traffic signal RSE capable of sending Signal Phase and Timing (SPaT), MAP, and other J2735-defined messages to pedestrians carrying mobile devices, and receiving PSMs (see (18), (19), (20), and (21) in the diagram).
2. Serve as a Transit Stop RSE capable of receiving PMMs sent over cellular and relaying this information to a Transit Management Center or directly to a transit vehicle, and sending transit-related traveler information to mobile devices.

Within the EPS, mobile devices will support several communications media for different purposes and data exchanges, all of which are transparent to a user, except the initial ride / travel request. A user will, as a minimum, need to enter the time and location of the start of the trip (departure time and departure location), the desired travel end location (destination location), any mobility needs (wheelchair or other such information), as well as desired transportation means (taxi, ride-share, or transit vehicle). Additionally, the user will also be able to view travel request acknowledgements to know that her/his request has been received. Lastly, users of mobile devices will receive advisories, alerts, and warnings on their mobile devices informing them of vehicles that might potentially pose a danger.
Mobile devices will also receive GNSS data to determine their location. Data obtained from GNSS includes latitude, longitude, speed, and heading.

The different communications media and resulting data exchanges include:

1. Mobile Device →In-Vehicle Devices (see (1) in the diagram): PSM, PMM, and Surrogate BSM messages will be sent from a mobile device to vehicles via DSRC if the vehicles are within DSRC range of the mobile device.
2. In-Vehicle Device → Mobile Devices (see (2), (3), and (4) in the diagram):
    a. BSM messages are broadcast from a vehicle and received by mobile devices (among others who might receive the BSM broadcast).
    b. A vehicle having received a PMM and agreeing to pick up ride/travel-requesting passengers will send a PMM response (PMM-RSP).
    c. Specially equipped vehicles (likely transit vehicles) equipped with limited short-range sensing technology such as Bluetooth iBeacon will send its presence (within the vehicle and right outside) to mobile devices allowing these to know they have (or are about to) enter(ed) the pickup vehicle (see (3) in the diagram). However, a mobile device cannot detect that it has actually entered a vehicle without additional information, such as the vehicle's acceleration and/or speed. Modern mobile devices inside of a vehicle can use sensors to detect motion that can be attributed to vehicle's movement.
    d. As a traveler approaches their destination, the vehicle will send a message to the traveler via Wi-Fi Direct (see (4) in the diagram).
3. Mobile Device → Mobile Devices (see (7) in the diagram): Coordination messages to create an ad-hoc travel group, maintain an ad-hoc travel group, and leaving an ad-hoc travel group will be sent between mobile devices in relative close proximity via Wi-Fi-Direct.
4. Mobile Device → Roadside Receiver (see (8) and (9) in the diagram):
    a. PSM and PMM messages will be sent from a mobile device to a nearby roadside receiver via DSRC to capture the message exchanges (see (9) in the diagram).
    b. Non-DSRC-capable mobile devices could send a message to the roadside receiver via Wi-Fi Direct (see (8) in the diagram)

5. Mobile Device → Cloud Infrastructure (see (12) and (16) in the diagram): PMM messages will be sent from a mobile device to the cloud infrastructure via cellular (if outside of DSRC range) to send a ride/travel request to vehicles capable of accepting passengers.
6. Cloud Infrastructure → Vehicle (see (17) and (13) in the diagram):
    a. PMM messages received from a mobile device via cellular will be sent from the cloud infrastructure to a vehicle via cellular to facilitate a ride/travel request to a vehicle capable of accepting passengers. The PMM message from a mobile device could also be send to a vehicle dispatching center first, which would determine the most suitable vehicle and dispatch that vehicle to the ride-requesting mobile device. The Cloud Infrastructure-to-Vehicle link is supposed to represent both possible approaches; however, the Vehicle-to-Cloud Infrastructure link is limited to sending an acknowledgement for a PMM ride-request from the ride-request responding vehicle via cellular to the ride-requesting mobile device.
    b. Alight Vehicle Messages could also be sent to the cloud via cellular to notify a passenger of an upcoming alighting location.
7. RSE → Cloud Infrastructure (see (14) and (23) in the diagram):
    a. BSMs, PSMs, PMMs, and Cross Street Request Messages received by RSE located at intersections or at a taxi or transit stop will be transmitted to the cloud infrastructure through backhaul. Transportation management agencies could access this data to actively manage their respective systems.

The details of the diagram have been captured and defined as system requirements in the following paragraphs.

3.3 System Constraints and Assumptions

The EPS is an experimental system that will be developed using the following constraints and assumptions:

1.) The EPS will include software applications running on mobile devices. The mobile device experimental application (MDEA) is a project-specific application running on a mobile device that performs functions such as populating PMM messages, receiving and displaying advisories, warnings, and alerts, performing calculations and algorithms, and transmitting / broadcasting information via the different communications media supported by the mobile device.
2.) The EPS will include software applications running in vehicles. The vehicle experimental application (VEA) is a project-specific application running in a vehicle that perform functions such as receiving PMM messages, receiving and displaying advisories, warnings, and alerts, performing calculations and algorithms, and transmitting / broadcasting information via the different communications media supported by the vehicle applications and sensors.
3.) Some demonstrations are expected to rely on decimeter-accuracy of the GNSS within the mobile devices and this will be tested / demonstrated. If the GNSS-based location accuracy cannot be achieved, the related tests will be executed using a method that would broadcast pre-programmed location information with the required accuracy, For example, if a pedestrian is to be detected when stepping into the roadway, but the GNSS accuracy is not sufficient, a manual input button in the MDEA will broadcast the location information needed to simulate the pedestrian stepping into the roadway.

4.) Some demonstrations rely on the detection of a mobile device entering and exiting a vehicle (passenger or transit vehicles) via various means, and the detection capabilities will be tested / demonstrated.
    a. If it is not possible to detect a mobile device entering a DSRC-equipped or otherwise equipped vehicle, the related tests will be executed using manual inputs simulating the entrance.
    b. Similarly, if it is not possible to detect a mobile device exiting a DSRC-equipped or otherwise equipped vehicle, the related tests will be executed using manual inputs simulating the exiting of the vehicle.
5.) The EPS demonstration relies on the available coverage of DSRC throughout the demonstration area. Should this not be possible, the demonstrations might not work correctly.
6.) The EPS demonstration relies on the available coverage of cellular communications throughout the demonstration area. Should this not be possible, the demonstrations might not work correctly.

3.4 Functional Requirements

The functional requirements to enablemobile devices to operate in the Connected Vehicle environment are defined in the next table. These functional requirements are a larger set of requirements than those required for use within the Experimental Prototype System (EPS) demonstration tests. A 'Y' indication means that the corresponding requirment is part of this task order's demonstration tests, while an 'N' indicates that the corresponding requirement is not.

Table 1: Functional Requirements Table

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
FR 1.0 Personal Safety Message (PSM) Functional Requirements			
FR 1.01	Broadcasting PSMs	Mobile devices shall broadcast PSMs via DSRC communications media.	Y
FR 1.02	PSM Broadcasting Frequency	Mobile devices shall be able to send PSMs in configurable transmission intervals in 0.1 second frequency intervals.	Y
FR 1.03	Stop broadcasting PSMs	Mobile devices shall stop broadcasting PSMs when the mobile device has detected to have entered a vehicle.	Y
FR 1.04	Restarting broadcasting PSMs	Mobile devices shall automatically restart the broadcast of the PSMs when exiting a vehicle.	Y
FR 1.05	Stop broadcasting PSMs	Mobile devices shall stop broadcasting PSMs when the mobile device has coordinated with a group leader (for crossing street or taxi/transit service). The sub-requirement below contains an exception to this rule.	Y
FR 1.06	Sending PSMs when in unsafe zone	A mobile device shall broadcast PSMs when the mobile device has detected that the pedestrian is in an unsafe zone. *NOTES:* - *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*	Y
FR 1.07	Restarting broadcasting PSMs	Mobile devices shall automatically restart the broadcast of the PSMs when the pedestrian signal indicates "Walk".	N

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
FR 1.08	PSM Transmit Timing	Mobile devices shall transmit PSMs only when the mobile device determines a vehicle is within a specified radius of the mobile device. The specified radius is dependent on the vehicle's speed. The radius calculation is the same as the advisory display distance, explained in 0. Note: This is in accordance with the J2945-9, Clause 6.3.3 standard.	Y
FR 2.0 Personal Mobility Message (PMM) Functional Requirements			
FR 2.01	Creating PMMs	A user of a mobile device shall be provided with an interface into the MDEA to enter trip request information.	Y
FR 2.01.01	Generating PMM Content	A user of a mobile device shall be able to enter their desired pickup time, pickup location, destination location, number of passengers included in the trip request, and mobility needs such as number of wheelchairs in party as part of the trip request information (PMM).	Y
FR 2.02	Sending PMMs	A mobile device shall send a PMM to an entity that can process the trip request. *Note: the PMM could be sent either to a dispatching center or directly to a vehicle.*	Y
FR 2.03	Transmitting PMMs over various communications media	A mobile device shall broadcast a PMM via various communications media, as defined by the following sub-requirements.	Y
FR 2.03.01	Transmitting PMMs – First Attempt – Communicate Directly with Vehicles in DSRC Range	A mobile device shall broadcast a PMM first over DSRC to potential passenger-transporting vehicles	Y
FR 2.03.02	Transmitting PMM – Second Attempt – Communicate with RSE via DSRC	If no response is received within a configurable amount of time from a passenger-transportation and responding vehicle, a mobile device shall broadcast the PMM to an RSE (connected to cloud infrastructure) via DSRC.	Y
FR 2.03.03	Transmitting PMM – Third Attempt – Communicate with RSE via Wi-Fi Direct	If no response is received within a configurable amount of time via an RSE, a mobile device shall broadcast the PMM to an RSE (connected to cloud infrastructure) via Wi-Fi Direct.	Y
FR 2.03.04	Transmitting PMM – Fourth Attempt – Communicate with Cloud Infrastructure via cellular	If no response is received within a configurable amount of time via either DSRC or Wi-Fi Direct, a mobile device shall send the PMM over cellular communications media to either a passenger-transport vehicle or a vehicle dispatch center, which in turn would dispatch a suitable vehicle.	Y
FR 2.04	Receiving a PMM acknowledgement receipt via DSRC	A mobile device shall be able to receive a PMM acknowledgement via DSRC.	Y
FR 2.05	Receiving a PMM acknowledgement receipt via cellular	A mobile device shall be able to receive a PMM acknowledgement via cellular communications media.	Y
FR 2.06	Generating PMM Response content	The PMM acknowledgement shall include the PMM Request ID of the original PMM trip request, Location of vehicle responding to the original PMM trip request, and an indicator whether the responding vehicle supports DSRC as a communications media.	Y
FR 2.07	Updating a PMM	A mobile device shall be able to create and transmit an updated PMM if new travelers have joined or left an ad-hoc travel group while ensuring that the PMM maintains its PMM unique identification number.	Y

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
FR 2.08	Manually cancelling a PMM	A mobile device shall be able to transmit a PMM-CANCEL if the traveler decides to cancel a trip.	Y
FR 2.09	Sending a PMM arrival message	A vehicle shall be able to create and transmit a PMM-ARRIVE message to the mobile device of the original PMM trip request at pre-configured intervals.	Y
FR 2.10	Receiving a PMM arrival message	A mobile device shall be able to receive a PMM-ARRIVE message from the vehicle responding to the original PMM trip request.	Y
FR 2.11	Sending PMM at a-location outside of DSRC range	A mobile device shall be able to transmit a PMM while "at home." *Note: "At home" generally refers to the residence of a traveler, but more specifically, refers to a location that is not in the vicinity of a taxi/transit stop, out of DSRC range of any connected vehicles and RSEs.* *Note: The EPS will operate under the constraint that the coordination of travel between mobile devices and vehicles will only occur at the pickup location, but for a fully deployed system, a mobile device should be able to send a PMM from any location.*	N
FR 3.0 Surrogate Basic Safety Message (Surrogate BSM) Functional Requirements			
FR 3.01	Generating Surrogate BSMs	Mobile devices shall be able to generate Surrogate BSMs when detecting the entrance into a non-equipped vehicle (passenger or transit).	N
FR 3.01.01	Generating Surrogate BSM Content	Mobile devices shall be able to generate the Surrogate BSM content including mobile device location, speed, heading, and an indicator that this message is a Surrogate BSM sent by a mobile device (and not a 'normal' BSM sent by a vehicle).	N
FR 3.02	Broadcasting Surrogate BSMs	Mobile devices shall be able to broadcast Surrogate BSMs to other equipped vehicles, equipped mobile devices, and other entities via DSRC communications media.	N
FR 3.03	Receiving Surrogate BSMs	Vehicles and mobile devices shall be able to receive Surrogate BSMs broadcasted by a mobile device located in non-equipped vehicles and transmitted via DSRC communications media.	N
FR 4.0 Basic Safety Message (BSM) Functional Requirements (those applicable to the Coordination of Moblie Devices in Connected Vehicle Applications)			
FR 4.01	Generating BSMs	Equipped vehicles shall be able to generate BSMs.	Y
FR 4.01.01	Generating BSM Content	Equipped vehicles shall be able to generate BSM content including vehicle location, vehicle speed, vehicle heading, and vehicle size, as a minimum.	Y
FR 4.02	Broadcasting BSMs	Equipped vehicles shall be able to transmit BSMs to other equipped vehicles, equipped mobile devices, and other entities via DSRC communications media.	Y
FR 4.03	Receiving BSMs	Mobile devices and equipped vehicles shall be able to receive BSMs broadcasted by vehicles via DSRC communications media.	Y
FR 5.0 Ad-hoc Travel Group Functional Requirements			
FR 5.01	Sending mobile device itinerary to other mobile devices	A mobile device shall be able to send its active PMM to other mobile devices via Wi-Fi-Direct communications media. *Note: Wifi Direct is an established communications mechanism and the mobile devices have to comply with this. The*	Y

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
		mechanism offers that mobile devices only need to 'register' once and then the registration is almost permanent.	
FR 5.01.01	Establish WiFi-Direct Communications	A mobile device shall follow the established procedures for WiFI-Direct communications to connect with other mobile devices in its vicinity.	Y
FR 5.01.02	Automatic reconnect to WiFi-Direct Communications	A mobile device shall be able to reconnect automatically to a previously existing WiFi-Direct Connection. The automatic reconnection shall not be limited by any elapsed time thresdhold of the disconnection.	Y
FR 5.01.03	Disconnect from WiFi-Direct Communications	A mobile device shall follow the established procedures for WiFI-Direct communications to disconnect from other mobile devices if the mobile device moves out of connection range.	Y
FR 5.02	Requesting the creation of an ad-hoc travel group	A mobile device shall automatically transmit a coordination request message to other mobile devices with the same PMM information in terms of departure location, departure time, and destination location to request the creation of an ad-hoc travel message. *Note: for the purpose of the EPS, the same itinerary means the exact same itinerary. Future research will have to determine whether locations along the path of a traveler are suitable to qualify for 'same' itinerary.*	Y
FR 5.03	Generating Travel Group Coordination Confirmation Message	A mobile device shall be able to generate and send an ad-hoc travel group coordination confirmation.	Y
FR 5.03.01	Generating Travel Group Coordination Confirmation Message Content	A mobile device shall be able to generate the coordination confirmation message content including the travel group creation request identifier, a travel group identifier, and a group status indicator.	Y
FR 5.04	Determining an ad-hoc travel group travel leader	The first mobile device to send a coordination confirmation message shall automatically become the travel group leader.	Y
FR 5.05	Limiting travel group size	The EPS shall include a capability within a mobile device's MDEA to limit the number of mobile devices that can be joined into an ad-hoc travel group.	Y
FR 5.06	Generating Travel Group Coordination Message	A mobile device shall be able to generate an ad-hoc travel group Coordination Message.	Y
FR 5.06.01	Generating Travel Group Coordination Message Content	A mobile device shall be able to generate the Coordination Message content including the travel group identifier, and a group status indicator.	Y
FR 5.07	Maintaining an ad-hoc travel group	A mobile device shall send a Coordination Message (coordination heartbeat message) to the travel group leader mobile device within a configurable frequency.	Y
FR 5.08	Leaving an ad-hoc travel group based on distance	The travel group leader's mobile device shall detect when another mobile device within the ad-hoc travel group leaves the travel group by exceeding the configurable distance between the travel group leader and the leaving group member and then automatically creates and sends an updated (group) PMM. *Note This might be simulated via a manual input into and sent from the leaving mobile device during the demonstration*.	Y
FR 5.09	Leaving an ad-hoc travel group based on request	The travel group leader's mobile device shall detect when another mobile device within the ad-hoc travel group requests to leave the travel group and then automatically creates and sends an updated (group) PMM.	Y

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
		Note This might be simulated via a manual input into and sent from the leaving mobile device during the demonstration.	
FR 5.10	Disbanding an ad-hoc travel group when entering a vehicle	A mobile device shall be able to detect when it enters a vehicle and automatically disjoin the ad-hoc travel group it belonged to (effectively dissolving the ad-hoc travel group).	Y
FR 5.11	Normal disbanding an ad-hoc travel group	The travel group leader's mobile device shall generate and send a coordination end message to all other mobile devices within the ad-hoc travel group when the group is to be dissolved for any other reasons than entering a vehicle and the distance between the travel group leader's mobile device and that of a group member exceeding a configurable distance. *Note This will be simulated via a manual input into and send from the travel group leader's mobile device during the demonstration*.	Y
FR 6.0 Entering and Leaving Light Duty Vehicle Functional Requirements			
FR 6.01	Detecting when entering DSRC equipped Light Duty vehicle	A mobile device shall be able to detect when it enters a DSRC-equipped Light Duty vehicle.	Y
FR 6.02	Detecting when entering non-DSRC equipped Light Duty vehicle	A mobile device shall be able to detect when it enters a non-DSRC-equipped Light Duty vehicle.	Y
FR 6.03	Detecting when exiting DSRC equipped Light Duty vehicle	A mobile device shall be able to detect when it exits a DSRC-equipped Light Duty vehicle.	Y
FR 6.04	Detecting when exiting non-DSRC equipped Light Duty vehicle	A mobile device shall be able to detect when it exits a non-DSRC-equipped Light Duty vehicle.	Y
FR 7.0 Entering and Leaving Transit Vehicle Functional Requirements			
FR 7.01	Detecting when entering DSRC equipped transit vehicle	A mobile device shall be able to detect when it enters a DSRC-equipped transit vehicle.	Y
FR 7.02	Detecting when entering non-DSRC equipped transit vehicle	A mobile device shall be able to detect when it enters a non-DSRC-equipped transit vehicle.	Y
FR 7.03	Detecting presence of Bluetooth connectivity in transit vehicle	A mobile device shall be able to detect the presence of Bluetooth communications media within a transit-vehicle when in proximity to or entering a transit vehicle.	Y
FR 7.04	Detecting when exiting DSRC equipped transit vehicle	A mobile device shall be able to detect when it exits a DSRC-equipped transit vehicle.	Y
FR 7.05	Detecting when exiting non-DSRC equipped transit vehicle	A mobile device shall be able to detect when it exits a non-DSRC-equipped transit vehicle.	Y
FR 8.0 Intersection/Crosswalk Positioning Functional Requirements			
FR 8.01	Detecting Intersection Corner Position	A mobile device shall be able to determine at which intersection corner it is positioned at an RSE-equipped intersection.	N
FR 8.02	Detecting Desired Crosswalk	A mobile device shall be able to determine which crosswalk the user desires to use at an RSE-equipped intersection.	N
FR 8.03	Detecting when entering a crosswalk	A mobile device shall be able to determine when it enters a crosswalk at an RSE-equipped intersection.	N
FR 9.0 Ad-hoc Intersection Crossing Group Functional Requirements			
FR 9.01	Sending Intersection Crossing Request to Intersection	A mobile device shall be able to send a Request to Cross Street Message to an intersection via DSRC communications media.	N

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
FR 9.02	Requesting the creation of an ad-hoc Intersection Crossing group	A mobile device shall automatically transmit a Request to Cross Street Message to other mobile devices via Wi-Fi-Direct	N
FR 9.03	Relaying Request to Cross Street Confirmation Message	A mobile device shall be able to relay a Request to Cross Street Confirmation Message received from an Intersection RSE to other mobile devices via Wi-Fi-Direct communications media.	N
FR 9.04	Determining an ad-hoc intersection crossing group leader	The first mobile device to send an Intersection Crossing Request message shall automatically become the intersection crossing group leader.	N
FR 9.05	Generating Intersection Crossing Group Coordination Message	A mobile device shall be able to generate all data elements required for a Request to Cross Street Message.	N
FR 9.05.01	Generating Intersection Crossing Group Coordination Message Content	A mobile device shall be able to generate the Request to Cross Street Message content including the the current corner location, intended crosswalk, and crossing speed.	N
FR 9.06	Disbanding an ad-hoc intersection crossing group	The intersection crossing group shall disband when the crosswalk changes to the “Walk” phase.	N
FR 10.0 Message Logging Functional Requirements			
FR 10.01	Recording all DSRC communications within RSE	A roadside unit (both intersection and transit stop-based) shall record all messages transmitted via DSRC communications media using millisecond-based timestamps of occurrence.	Y
FR 10.02	Recording all cellular communications via cloud infrastructure system	The cloud infrastructure shall capture and record all messages sent via cellular communications media using millisecond-based timestamps of occurrence.	Y
FR 10.03	Recording all sent and received communications within Mobile Device	A mobile device shall record all messages transmitted and received over any communications media using millisecond-based timestamps of occurrence.	Y
FR 10.04	Recording all displayed messages within Mobile Device	A mobile device shall record any information output to the screen of the mobile device using millisecond-based timestamps of occurrence.	Y
FR 10.05	Recording all sent and received communications within Vehicle	A vehicle shall record all messages transmitted and received over any communications media using millisecond-based timestamps of occurrence.	Y
FR 10.06	Recording all displayed messages within vehicle	A vehicle shall record any information output to the screen of the vehicle’s on-board device using millisecond-based timestamps of occurrence.	Y
FR 11.0 Safety Functional Requirements (applicable to the EPS)			
FR 11.01	Displaying Advisory within Vehicle	A vehicle shall display an advisory to the vehicle driver when it receives a PSM.	Y
FR 11.02	Displaying Alert within Vehicle	A vehicle shall display an alert to the vehicle driver when the vehicle receives a PSM and determines that it is approaching the mobile device and the mobile device is in an unsafe zone. The alert is displayed. The distance (between vehicle and mobile device) at which an alert is displayed is dependent on the vehicle’s speed, explained in 0.	Y
FR 11.03	Displaying Warning within Vehicle	A vehicle shall display a warning to the vehicle driver when the vehicle receives a PSM and determines that it is approaching the vulnerable road user and the vulnerable road user is in the vehicle’s lane of travel. The distance (between vehicle and mobile device) at which a warning is displayed is dependent on the vehicle’s speed, explained in 0.	Y

FR ID	Functional Requirement Title	Functional Requirement Description	EPS Req
FR 11.04	Displaying Advisory within Mobile Device	A mobile device shall display an advisory when it has received a BSM and determines that a vehicle is approaching. The distance (between vehicle and mobile device) at which an advisory is displayed is dependent on the vehicle's speed, explained in 0.	Y
FR 11.05	Displaying Alert within Mobile Device	A mobile device shall display an alert when it has received a BSM and determines that a vehicle is approaching and the mobile device is in an unsafe zone. The distance (between vehicle and mobile device) at which an alert is displayed is dependent on the vehicle's speed, explained in 0.	Y
FR 11.06	Displaying Warning within Mobile Device	A mobile device shall display an alert when it has received a BSM and detects that a vehicle is approaching and the mobile device is in the vehicle's lane of travel. The distance (between vehicle and mobile device) at which a warning is displayed is dependent on the vehicle's speed, explained in 0.	Y
FR 11.07	Display Pedestrian in Crosswalk Warning within Vehicle	A vehicle shall display a Pedestrian in Crosswalk Warning to the vehicle driver when the vehicle is approaching an intersection and the vehicle detects that a pedestrian is in the crosswalk crossing against the pedestrian signal.	N
FR 11.08	Display Pedestrian in Crosswalk Warning within Mobile Device	A mobile device shall display a Pedestrian in Crosswalk Warning to the pedestrian when the mobile device detects that the pedestrian is in the crosswalk crossing against the pedestrian signal (pedestrian's signal indication is not WALK).	N

Source: Battelle

3.5 System Interface Requirements

As shown under Figure 1, many different data exchanges must be performed within the EPS. The resulting requirements are defined both in terms of communications media and data contents. And as with the Functional Requirements, the system interface requirements defined in Table 2 and Table 34 are a larger set of requirements than those required for use within the Experimental Prototype System (EPS) demonstration tests. A 'Y' indication means that the corresponding requirment is part of this task order's demonstration tests, while an 'N' indicates that the corresponding requirement is not.

Requirements for the Vehicle-initiated Basic Safety Message (BSM) are listed for completeness reasons to indicate whether any J2735:2016-defined OPTIONAL Data Frames and/or Data Elements within the BSM are needed to fulfill the EPS goals and objectives.

Table 2: System Interface Requirements Table

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
SIR 1.0 Personal Safety Message (PSM) Requirements			
SIR 1.01	PSM Broadcasting Frequency	The PSM shall be broadcasted in user-defined transmission intervals adjustable in 0.1 second intervals.	Y

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
		Note: This is consistent with SAE J2735 standard for broadcast frequency, although the frequency is not defined (unlike the BSM where the frequency is required to be 0.1 seconds).	
SIR 1.02	PSM Location (lat/long/elev)	The PSM shall specify the pedestrian location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid. *Note: This is consistent with SAE J2735 PSM definition for location.*	Y
SIR 1.03	PSM Speed	The PSM shall specify the pedestrian speed in meters/second in 0.1 m/s increments. *Note: This is consistent with the SAE J2735 PSM definition for speed.*	Y
SIR 1.04	PSM Heading	The PSM shall specify the pedestrian heading, expressed in signed units of 0.0125 degrees from North (same units as in BSMs). *Note: This is consistent with SAE J2735 PSM definition for heading.*	Y
SIR 1.05	PSM Number of Pedestrians	The PSM shall specify a number of travel group members included in the PSM. *Note: This field will increase/decrease as travelers join/disband from a travel group. The group leader would be sending a PSM for the entire group. There is an optional field in the SAE J2735 PSM definition called 'NumberOfParticipantsInCluster' but only defines small (2-5 people), medium (6-10 people), or large groups (>10).*	Y
SIR 1.06	PSM Radius of Protection	The PSM shall specify a 'radius of protection' expressed in 0.1 meter increments that is reflective of the number of pedestrians included in the PSM. *Note: This is consistent with SAE J2735 PSM definition for PersonalClusterRadius defining the radius in meters around a cluster of users.*	Y
SIR 1.07	PSM Radius of Protection expandable	The PSM 'radius of protection' shall be expandable, depending on *the number of pedestrians included in the PSM.* *Note: This is consistent with SAE J2735 PSM definition for PersonalClusterRadius defining the radius in meters around a cluster of users.*	Y
SIR 1.08	PSM Path History	The PSM shall specify the pedestrian path history for up to the last 20 seconds. *Note: This is consistent with SAE J2735 PSM definition for path history although J2735 does not specify the length of the path history to include. We are limiting this to 20 seconds and even that might be too long for this project*	Y
SIR 1.09	PSM Path Prediction	The PSM shall specify the pedestrian path prediction for up to the next 5 seconds. *Note: This is consistent with SAE J2735 PSM definition for path prediction, although J2735 does not specify the prediction time into the future. We are limiting this to 5 seconds because non-motorized travel is highly variable and hard to predict.*	Y
SIR 2.0 Personal Mobility Message (PMM) Requirements			
SIR 2.01	PMM Request ID	The PMM shall specify a unique Request ID.	Y

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
SIR 2.02	PMM Location (lat/long/elev)	The PMM shall specify the pedestrian location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid.	Y
SIR 2.03	PMM Number of Travelers	The PMM shall specify the number of travelers included in the PMM.	Y
SIR 2.04	PMM Pickup Time	The PMM shall specify the pickup time expressed in Universal Coordinated Time (UTC) in 0.1 second increments.	Y
SIR 2.05	PMM Pickup Location	The PMM shall specify the pickup location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). *NOTE: this does not define how a mobile device user might actually select the location via the display of the mobile device.*	Y
SIR 2.06	PMM Destination	The PMM shall specify destination location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). *NOTE: this does not define how a mobile device user might actually select the location via the display of the mobile device.*	Y
SIR 2.07	PMM Mode of Transport	The PMM shall specify a preferred method of desired transportation from the following (values are mutually exclusive): - Transit - Taxi - Ride-sharing service - No preference	Y
SIR 2.08	PMM Mobility Needs	The PMM shall specify any mobility needs requirements from the following (values are not mutually exclusive): - Wheelchair - Needs Seat - No special needs *NOTE: other mobility needs can be listed within an updated version at a later time.*	Y
SIR 2.09	PMM ETA Threshold	The PMM shall allow a user to enter a maximum acceptable deviation value for the originally issued Estimated Time of Arrival (contained in the PMM-RSP Message). *Note: Should this value be exceeded, the responding vehicle application will reissue the PMM Arrive message.*	N
SIR 3.0 Personal Mobility Acknowledgement Message (PMM-RSP) Requirements			
SIR 3.01	PMM-RSP Request ID	The PMM-RSP shall contain the same unique Request ID used in the PMM to which the PMM-RSP responds.	Y
SIR 3.02	PMM-RSP Location	The PMM-RSP shall specify the location of the vehicle responding to the PMM, expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid.	Y
SIR 3.03	PMM-RSP DSRC Support Indicator	The PMM-RSP shall specify whether the responding vehicle is capable of sending BSM and other messages over DSRC with allowable values of: - 0 = no DSRC support	Y

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
		- 1 = DSRC support	
SIR 4.0 Personal Mobility Cancel Message (PMM-CANCEL) Requirements			
SIR 4.01	PMM-CANCEL Request ID	The PMM- CANCEL shall contain the same unique Request ID used in the PMM to which the PMM- CANCEL responds.	Y
SIR 5.0 Personal Mobility Arrival Estimate Message (PMM-ARRIVE) Requirements			
SIR 5.01	PMM-ARRIVE Request ID	The PMM-ARRIVE shall contain the same unique Request ID used in the PMM to which the PMM-ARRIVE responds.	Y
SIR 5.02	PMM-ARRIVE Location (lat/long/elev)	The PMM-ARRIVE shall specify the location of the vehicle responding to the PMM, expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum).	Y
SIR 5.03	PMM-ARRIVE ETA	The PMM-ARRIVE shall specify the estimated time of arrival of the vehicle responding to the PMM, expressed in 1 second increments.	N
SIR 5.04	PMM-ARRIVE Visible Vehicle ID	The PMM-ARRIVE shall specify a visible indication of the vehicle responding to the PMM, expressed as free form text. *Note: this text field will only be completed once by the vehicle operator and will be used by the receiving PMM-originating mobile device so that the traveler can visibly identify the vehicle.*	Y
SIR 6.0 Surrogate Basic Safety Message (Surrogate BSM) Requirements			
SIR 6.01	Surrogate BSM Location (lat/long/elev)	The Surrogate BSM shall specify the passenger location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid.	N
SIR 6.02	Surrogate BSM Speed	The Surrogate BSM shall specify the passenger speed in meters/second in 0.1 m/s increments.	N
SIR 6.03	Surrogate BSM Heading	The Surrogate BSM shall specify the passenger heading, expressed in unsigned units of 0.0125 degrees from North (same units as in BSMs)..	N
SIR 6.04	Surrogate BSM Indicator	The Surrogate BSM shall specify that it is a Surrogate BSM by including a Surrogate BSM indicator in message broadcast, with the potential, mutually exclusive values of: - 0 = not a Surrogate BSM - 1 = Surrogate BSM	N
SIR 7.0 Basic Safety Message (BSM) Requirements (those applicable to the EPS)			
SIR 7.01	BSM Location (lat/long/elev)	The BSM shall specify the vehicle location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid.	Y
SIR 7.02	BSM Speed	The BSM shall specify the vehicle speed in meters/second in 0.1 m/s increments.	Y
SIR 7.03	BSM Heading	The BSM shall specify the vehicle heading, expressed in unsigned units of 0.0125 degrees from North such that 28799 such degrees represent 359.9875 degrees. North shall be defined as the axis prescribed by the WGS-84 coordinate system and its reference ellipsoid. Headings "to the east" are defined as the positive direction. A value of 28800 shall be used when unavailable.	Y

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
SIR 7.04	BSM Vehicle Size	The BSM shall specify the width and length of the vehicle, expressed in 1 cm increments.	Y
SIR 7.05	BSM Vehicle Travel Lane	The BSM shall indicate the vehicle's lane of travel.	N
SIR 8.0 Coordination Messages for Ad-hoc Travel Groups Requirements			
SIR 8.01	Coordination Message types using the same travel group ID	Coordination message types for the same Ad-hoc Travel Group shall use the same unique, randomly assigned identification number for the duration that the ad-hoc travel group exists.	Y
SIR 8.02	Coordination Request Message ID	The coordination request message shall include a unique, randomly assigned identification number.	Y
SIR 8.03	Coordination Request Number of Requesters	The coordination request message shall specify the number of pedestrians included in the group making this request to join others in an Ad-hoc travel group.	Y
SIR 8.04	Coordination Request Pickup Time	The coordination request message shall specify the pickup time expressed in UTC time in 1 minute increments.	Y
SIR 8.05	Coordination Request Pickup Location (lat/long/elev)	The coordination request message shall specify the pickup location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid. *NOTE: this does not define how a mobile device user might actually select the location via the display of the mobile device.*	Y
SIR 8.06	Coordination Request Destination (lat/long/elev)	The coordination request message shall specify destination location expressed in 1/10th integer microdegrees (longitude and latitude with reference to the horizontal datum). Elevation shall be expressed in signed units of 10 cm steps above or below the reference ellipsoid. *NOTE: this does not define how a mobile device user might actually select the location via the display of the mobile device.*	Y
SIR 8.07	Coordination Request Mode of Transport	The coordination request message shall specify a preferred method of desired transportation from the following (values are mutually exclusive): - Transit - Taxi - Ride-sharing service - No preference	Y
SIR 8.10	Coordination Confirmation Message ID	The coordination confirmation message shall include the same unique, randomly assigned identification number as in the Coordination Request message.	Y
SIR 8.11	Coordination Confirmation Travel Group ID	The coordination confirmation message shall include a unique, randomly assigned identification number for an ad-hoc travel group, which is assigned by the travel group leader's mobile device.	Y
SIR 8.20	Coordination Heartbeat Message ID	The coordination heartbeat message shall include the same unique, randomly assigned identification number as in the Coordination Request message.	Y
SIR 8.21	Coordination Heartbeat Travel Group ID	The coordination heartbeat message shall include a unique, randomly assigned identification number for an ad-hoc travel group, which is assigned by the travel group leader's mobile device.	Y

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
SIR 8.22	Coordination Heartbeat Frequency	The coordination heartbeat message shall be send in user – definable .	Y
SIR 8.30	Coordination End Message ID	The coordination end message shall include the same unique, randomly assigned identification number as in the Coordination Request message.	Y
SIR 8.31	Coordination End Travel Group ID	The coordination end message shall include a unique, randomly assigned identification number for an ad-hoc travel group, which is assigned by the travel group leader's mobile device.	Y
SIR 9.0 Signal Phase and Timing (SPaT) Message Requirements			
SIR 9.01	SPaT Broadcasting Frequency	The SPaT Message shall be broadcasted once every second.	Y
SIR 9.02	Status of Signal Controller	The SPaT Message shall contain information regarding the status of the signal controller, including at a minimum, the cycle time, the current time in the cycle, and timing plans for all approaches, including pedestrians.	Y
SIR 9.03	Prediction of Duration and Phases	The SPaT Message shall contain a prediction of the timing and duration of upcoming phases.	Y
SIR 10.0 MAP Message Requirements			
SIR 10.01	MAP Broadcasting Frequency	The MAP Message shall be broadcasted once every 5 seconds.	Y
SIR 10.02	Geographic information for Lanes in Intersection	The MAP Message shall contain geographic information for all movements (connecting approaches) in the intersection.	Y
SIR 10.03	Geographic information for Lanes for approaches	The MAP Message shall contain geographic information for all lanes for all approaches.	Y
SIR 10.04	Types of Lanes	The MAP Message shall contain information about each lane type of each lane (e.g. vehicle, bike, pedestrian, etc.)	Y
SIR 11.0 Alight Vehicle Message Requirements			
SIR 11.01	Request ID	The Alight Vehicle Message shall contain the same unique request ID used in the original PMM that was used to coordinate the trip.	N
SIR 11.02	Exit Location	The Alight Vehicle Message shall contain the exit location (by name or by latitude/longitude)	N
SIR 11.03	Time to Arrival Estimation	The Alight Vehicle message shall contain an approximation of the amount of time until the passenger is expected to alight the vehicle.	N
SIR 12.0 Request to Cross Street Message			
SIR 12.01	Request ID	The Request to Cross Street Message shall specify a unique Request ID	N
SIR 12.02	Intersection Corner Indicator	The Request to Cross Street Message shall specify which intersection corner the pedestrian is currently on.	N
SIR 12.03	Crosswalk Indicator	The Request to Cross Street Message shall specify which crosswalk the pedestrian intends to use.	N
SIR 12.04	Number of Pedestrians	The Request to Cross Street Message shall specify the number of pedestrians in the crossing group.	N
SIR 12.05	Minimum Pedestrian Crossing Speed	The Request to Cross Street Message shall specify the crossing speed of the group member with the slowest crossing speed.	N
SIR 13.0 Crossing Street Acknowledgement Message			

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
SIR 13.01	Request ID	The Crossing Street Acknowledgement Message shall contain the same unique request ID used in the original Request to Cross Street Message that was used to coordinate the crossing.	N
SIR 14.0 Traveler Information Requirements			
SIR 14.01	Broadcasting Frequency	Traveler Information (e.g. weather information, car share information, bike share availability, etc.) shall be broadcasted once every 60 seconds from Transit Stop RSE.	N
SIR 15.0 Data Exchange Communications Media System Interface Requirements			
SIR 15.01	PSM over DSRC	The EPS shall support the exchange of PSM via DSRC communications media.	Y
SIR 15.02	PMM, PMM-RSP, PMM-CANCEL over DSRC	The EPS shall support the exchange of the PMM, PMM-RSP, and PMM-CANCEL via DSRC communications media.	Y
SIR 15.03	PMM, PMM-RSP, PMM-CANCEL over Wi-Fi Direct	The EPS shall support the exchange of the PMM, PMM-RSP, and PMM-CANCEL via Wi-Fi Direct communications media.	N
SIR 15.04	PMM, PMM-RSP, PMM-CANCEL over Cellular	The EPS shall support the exchange of the PMM, PMM-RSP, and PMM-CANCEL via cellular communications media.	Y
SIR 15.05	PMM-ARRIVE over DSRC	The EPS shall support the exchange of the PMM-ARRIVE via DSRC communications media.	Y
SIR 15.06	Surrogate BSM over DSRC	The EPS shall support the exchange of the Surrogate BSM via DSRC communications media.	N
SIR 15.07	BSM over DSRC	The EPS shall support the exchange of the BSM via DSRC communications media.	Y
SIR 15.08	Any Coordination Message type over Wi-Fi-Direct	The EPS shall support the exchange of any Coordination Message type (Coordination Request, Coordination Confirmation, Coordination Heartbeat, and Coordination End messages) via Wi-Fi-Direct communications media.	Y
SIR 15.09	Mobile Device Detection via Bluetooth iBeacon	The EPS shall support the detection of Bluetooth-enabled mobile devices via Bluetooth communications media using Bluetooth iBeacon technology when entering a Bluetooth iBeacon-equipped vehicle. *Note: for the EPS, only transit vehicles will be equipped with Bluetooth iBeacon technology.*	Y
SIR 15.10	SPaT over DSRC	The EPS shall support the exchange of Signal Phase and Timing (SPaT) messages via DSRC communications media.	Y
SIR 15.11	MAP over DSRC	The EPS shall support the exchange of MAP messages via DSRC communications media.	Y
SIR 15.12	Exit Vehicle Message over Wi-Fi Direct	The EPS shall support the exchange of Exit Vehicle Messages via Wi-Fi Direct	N
SIR 15.13	Request to Cross Street over DSRC	The EPS shall support the exchange of Request to Cross Street Messages via DSRC communications media.	N
SIR 15.14	Crossing Street Acknowledgement over DSRC	The EPS shall support the exchange of Crossing Street Acknowledgement Messages via DSRC communications media.	N
SIR 16.0 Recording Interface Requirements			
SIR 16.01	RSE to receive all DSRC communications	A roadside unit shall be able to receive all messages transmitted via DSRC communications media.	Y
SIR 16.02	Cloud Infrastructure equipment to receive all cellular communications	A cloud infrastructure equipment shall be able to receive all messages sent via cellular communications media.	Y

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS Req
SIR 17.0 General System Interface Requirements			
SIR 17.01	Conform to existing, standardized data element definitions	The data elements used to transfer data from one EPS component to another shall be drawn from existing data exchange standards to the maximum extent possible.	Y
SIR 17.01.01	Use J2735:2016 if MSGs and DEs fulfill requirements	The data elements, if defined and fulfilling all other System Interface requirements, shall be drawn from existing interface standards and guidance documents including: • SAE J2735:2016 published version • SAE J2945/1:2016 published version • SAE J2945/9 (November 2016 draft)	Y

Source: Battelle

In addition to defining the System Interface Requirements for the exchange of data, data exchange sequence definitions are important to enable interoperable data exchanges. In order to accomplish interoperable data exchanges, the following data exchange sequences will be implemented within the EPS. The System Interface Requirement titles for these data exchange sequences are first defined in Table 4 and further explained within UML Diagrams and descriptions following the table.

Simple data exchanges across interfaces within the EPS are not listed in the table, because these simply involve actions such as monitoring of data exchanges for logging purposes and/or broadcasting of data within vehicle-originating Basic Safety Message (BSM) and mobile device-originating Personal Safety Message (PSM) transmissions.

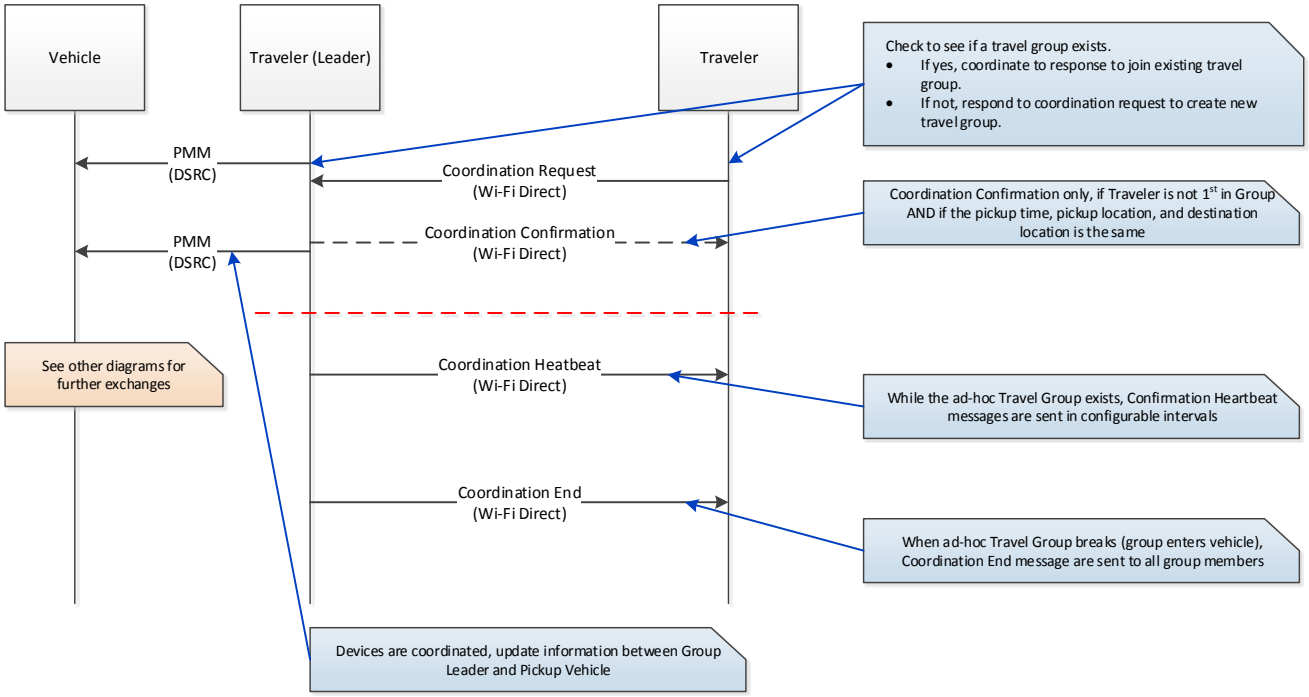
Table 3: System Interface Data Exchange Sequence Requirements Table

SIR ID	System Interface Requirement Title	System Interface Requirement Description	EPS
SIR 20.0 Data Exchange Sequences			
SIR 20.01	Forming and Splitting of Travel Groups	Defines the data exchange sequence for forming and splitting of travel groups. This includes the ad-hoc determination of the travel 'group leader' mobile device, which will retain the communications with devices outside of the travel group.	Y
SIR 20.02	Changing a Travel Group Leader	Defines the data exchange sequence for changing of a travel group leader within a travel group.	N
SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	Defines the data exchange sequence to request and enter a Light Duty vehicle that has DSRC equipment on board.	Y
SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	Defines the data exchange sequence to request and enter a Light Duty vehicle that does not have DSRC equipment on board.	N
SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	Defines the data exchange sequence to request and enter a DSRC-equipped transit vehicle that is also equipped with a Bluetooth iBeacon.	Y
SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	Defines the data exchange sequence to request and enter a transit vehicle that has no DSRC equipment on board, but that is equipped with a Bluetooth iBeacon.	N
SIR 20.07	Requesting and Crossing a Street at an RSE-equipped Intersection	Defines the data exchange sequence to request and cross a RSE-equipped intersection capable of broadcasting SPaT and MAP messages.	N

Source: Battelle

Forming and Splitting of Travel Groups

The following UML diagram defines the data exchange sequence for forming and splitting of travel groups, which is followed by a description.



Source: Battelle

Figure 2. UML Diagram – Forming and Ending travel groups

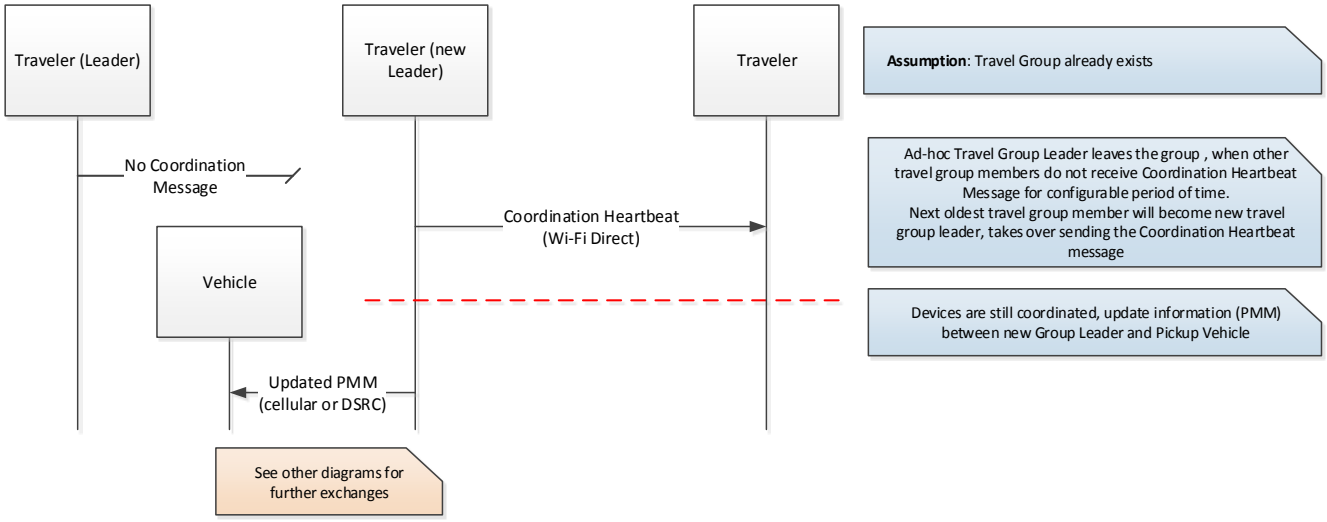
The steps shown in the above UML Diagram are explained in the following paragraphs:

1. A mobile device sending out ride / travel request messages (PMM) will also broadcast a Coordination Request Message, which will contain similar contents as a PMM, via Wi-Fi-Direct communications media to determine, if there are other mobile devices within the vicinity with the same departure time, departure location, and destination location. *Wi-Fi-Direct is proposed, because it can be loaded into modern smartphones, does not require the presence of a Wi-Fi Access Point, does not require a user-initiated Wi-Fi Access Point connection, and is limited in range. Other communications media normally present in a modern smartphone have un-desirable limitations such as the need to manually pair with other devices (Bluetooth) and/or distance limitations with Near Field Communications (NFC).*
2. If another mobile device receives a Coordination Request Message with the same time, departure and destination information, the mobile devices will transparently exchange coordination messages to agree to create an ad-hoc travel group and which mobile device will become the travel group leader. Other mobile devices might joint as needed.
3. Once the travel group leader mobile device is determined, it will update its PMM with the number of travelers in the group and any mobility needs that might be necessary, and transmit it either over cellular or DSRC to a vehicle.
4. The travel group leader's mobile device will then send out periodic Coordination Heartbeat Messages to maintain the travel group.
5. If the travel group enters a vehicle, the travel group leader's mobile device will send a Coordination End message to all other mobile devices within the ad-hoc travel group. *Note that this last message is not necessarily needed (travel group could resolve simply by all mobile devices drifting apart by distance and time (no heartbeat message), but for the*

purpose of the demonstration, ending a test procedure with a defined end was seen as more practical.

Changing a Travel Group Leader

The following UML diagram defines the data exchange sequence for changing a travel group leader within a travel group, which is succeeded by a description.



Source: Battelle

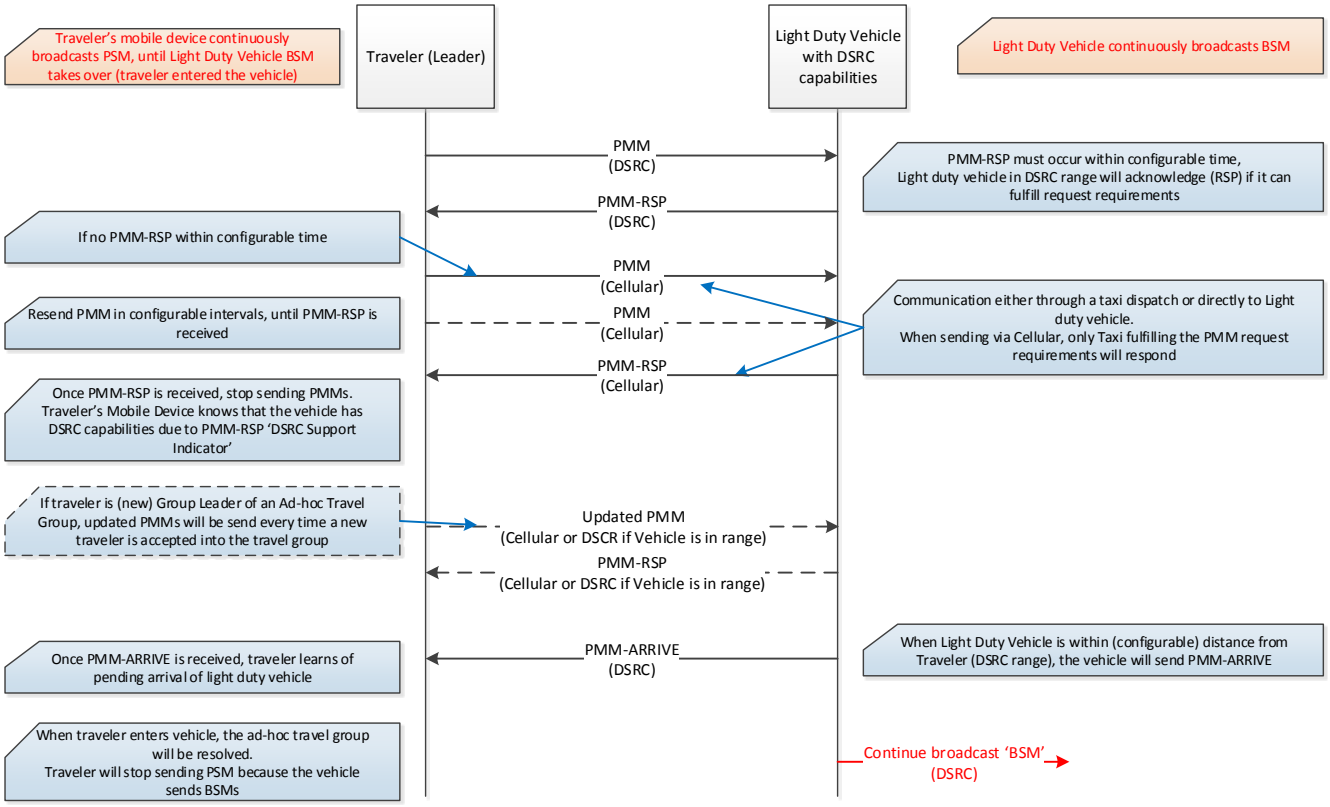
Figure 3. UML Diagram – Changing a travel group leader

The steps shown in the above UML Diagram are explained in the following paragraphs:

1. Traveler who is currently the travel group leader decides to leave the group.
2. All devices determine that the Coordination Heartbeat message has been absent for too long.
3. The mobile device that was added to the group next at the time of group formation (next oldest member) then steps up as leader and sends an updated PMM to the approaching vehicle (group size is now reduced).

Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle

The following UML diagram defines the data exchange sequence for requesting and entering a Light Duty vehicle equipped with DSRC equipment, which is succeeded by a description.



Source: Battelle

Figure 4. UML Diagram – Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle

The steps shown in the above UML Diagram are explained in the following paragraphs:

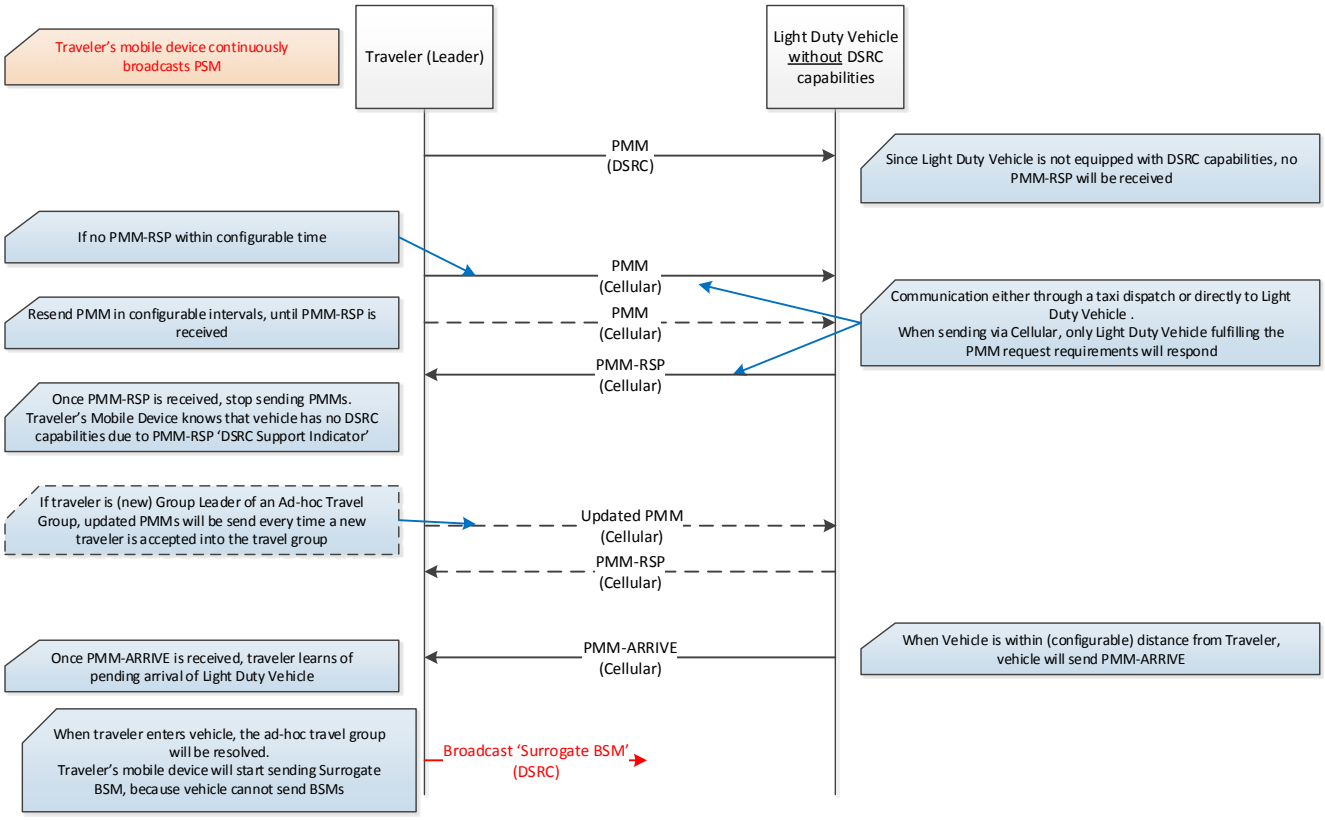
1. If the geographic location of the user entering the ride/travel request (PMM) information is outside of the range of a responding vehicle over DSRC (no PMM-RSP received via DSRC), the PMM information will be send over cellular (3G or 4G/LTE depending on availability) and transmitted via the cloud infrastructure ultimately to a passenger-transporting vehicle.
   Note that the data could be sent to a transit dispatch center, which informs the approaching passenger-transporting vehicle.
2. Once a mobile device sending a PMM is within the range of a responding vehicle over DSRC (PMM-RSP received via DSRC), the ride / travel request message will be transmitted over DSRC communications.
3. If a vehicle, which has DSRC equipment on-board, comes into DSRC range and receives a PMM, which indicates that the travel group is larger than the capacity, or has persons with mobility limitations that the vehicle cannot fulfill, the vehicle will send a PMM- RSP with availability information.
4. Should a mobile device again move outside of DSRC range, the ride / travel request message will be sent over cellular.
5. A vehicle having received a ride / transit request message and capable to fulfill the (new or updated) ride / travel request requirements will create and send a PMM response (PMM

RSP) message over either cellular (if outside of DSRC range) or DSRC (if within DSRC range).

6. The travel group leader mobile device that sent the PMM will receive the PMM RSP over either cellular or DSRC and, in response, will cease to send PMMs.
7. Should additional mobile devices with the same itinerary (same coordination request message contents) join the travel group, the travel group team leader mobile device will send updated PMMs with the new number of travel group members to the approaching vehicle.
8. When the vehicle comes into the configurable range from the PMM requester location, it will send an arrival message (PMM-ARRIVE) to the travel group leader mobile device.
9. During the whole process, the vehicle continues to send the vehicle-specific BSM.

Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle

The following UML diagram defines the data exchange sequence for requesting and entering a Light Duty vehicle not equipped with DSRC equipment, which is succeeded by a description.



Source: Battelle

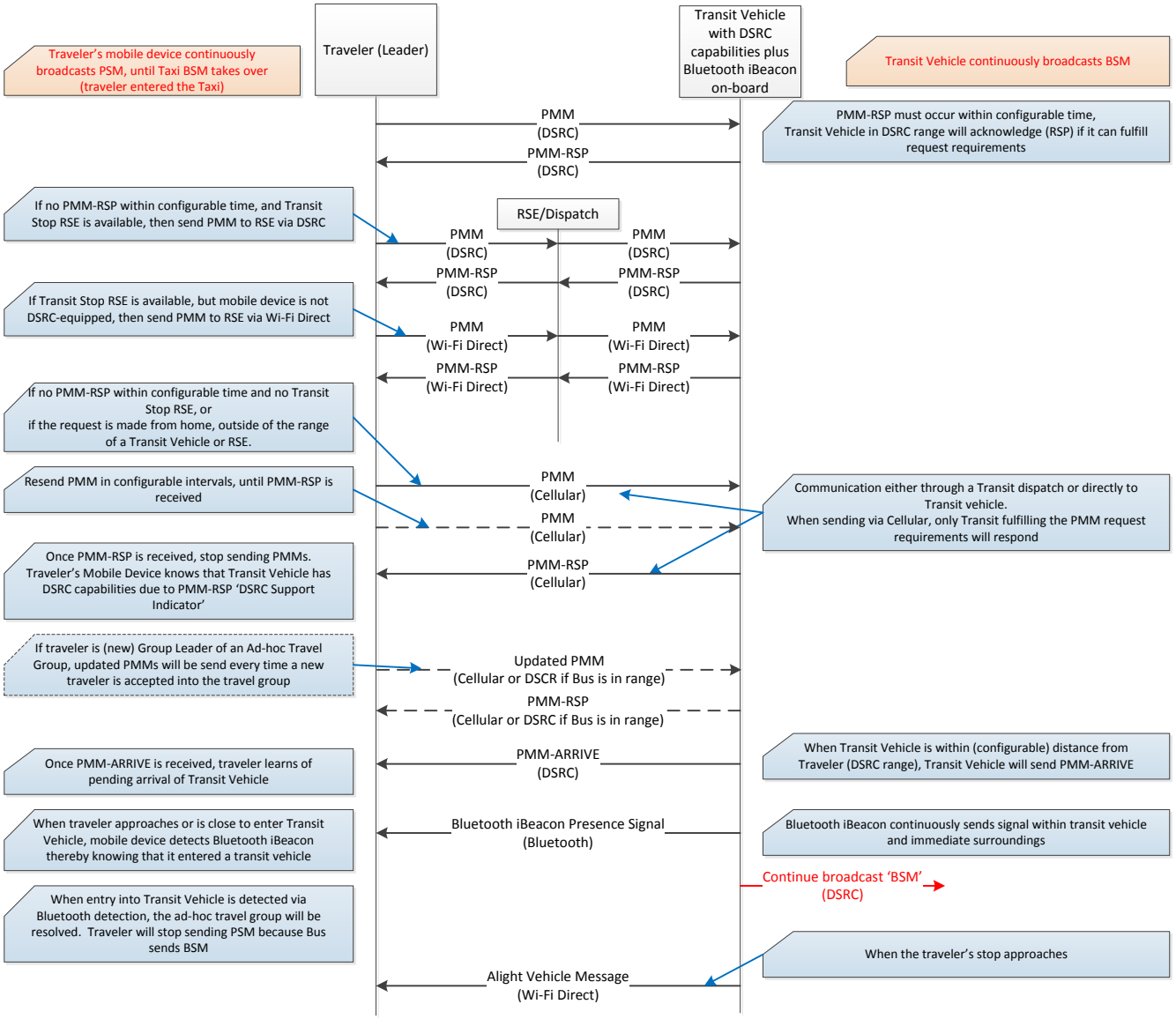
Figure 5. UML Diagram – Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle

The data exchange sequence shown above is similar to the data exchange sequence shown in Figure 4, with the difference that the approaching Light Duty vehicles does not have any DSRC equipment on-board. The steps shown in the above UML Diagram are explained in the following paragraphs:

1. The mobile device sends a PMM over DSRC but receives no response from the Light Duty vehicle.
2. After a configurable duration has passed, the mobile device assumes that there is no Light Duty vehicle with DSRC capabilities nearby. In response, the mobile device sends its PMM request via cellular and continues to send the PMM request until a response from a light duty vehicle is received via cellular.
   Note: again, the PMM message over cellular could have first been sent via a dispatch center to the Light Duty vehicle.
3. If the geographic location of the user entering the ride/travel request (PMM) information is outside of the range of a responding vehicle over DSRC (no PMM-RSP received via DSRC), the information will be sent over cellular (3G or 4G/LTE depending on availability) and transmitted via the cloud infrastructure ultimately to a passenger-transporting vehicle.
   Note that the data could be sent to a transit dispatch center, which informs the approaching passenger-transporting vehicle.
4. A vehicle having received a ride / transit request message and capable to fulfill the (new or updated) ride / travel request requirements will create and send a PMM response (PMM RSP) message over cellular.
5. The travel group leader mobile device that sent the PMM will receive the PMM RSP over cellular and, in response, will cease to send PMMs.
6. Should additional mobile devices with the same itinerary (same coordination request message contents) join the travel group, the travel group team leader mobile device will send updated PMMs with the new number of travel group members to the approaching vehicle.
7. When the vehicle comes into the configurable distance range (calculated by the vehicle application based on comparing the traveler request with its own position), the vehicle will send an arrival message (PMM-ARRIVE) to the travel group leader mobile device.
8. After the traveler(s) enter the vehicle and knowing that the vehicle is not equipped with DSRC capabilities, the mobile device of the travel group leader, which might or might not be the mobile device of the previous travel group leader, having stopped sending PSMs, generates and starts to send a Surrogate BSM, which contains a subset of vehicle's BSM message contents and includes an indicator that this message is not a BSM generated by a vehicle.
   For example, the mobile device cannot know anything about a vehicles steering wheel angle or the vehicle's size (width and length).

Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle

The following UML diagram defines the data exchange sequence for requesting and entering a DSRC-equipped transit vehicle, which is succeeded by a description.



Source: Battelle

Figure 6. UML Diagram – Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle

The data exchange sequence shown above is similar to the data exchange sequence shown in Figure 4, with the difference that the approaching vehicle is a transit vehicle which supports DSRC communications and includes a Bluetooth iBeacon to allow a mobile device to determine whether it entered a vehicle. The steps shown in the above UML Diagram are explained in the following paragraphs:

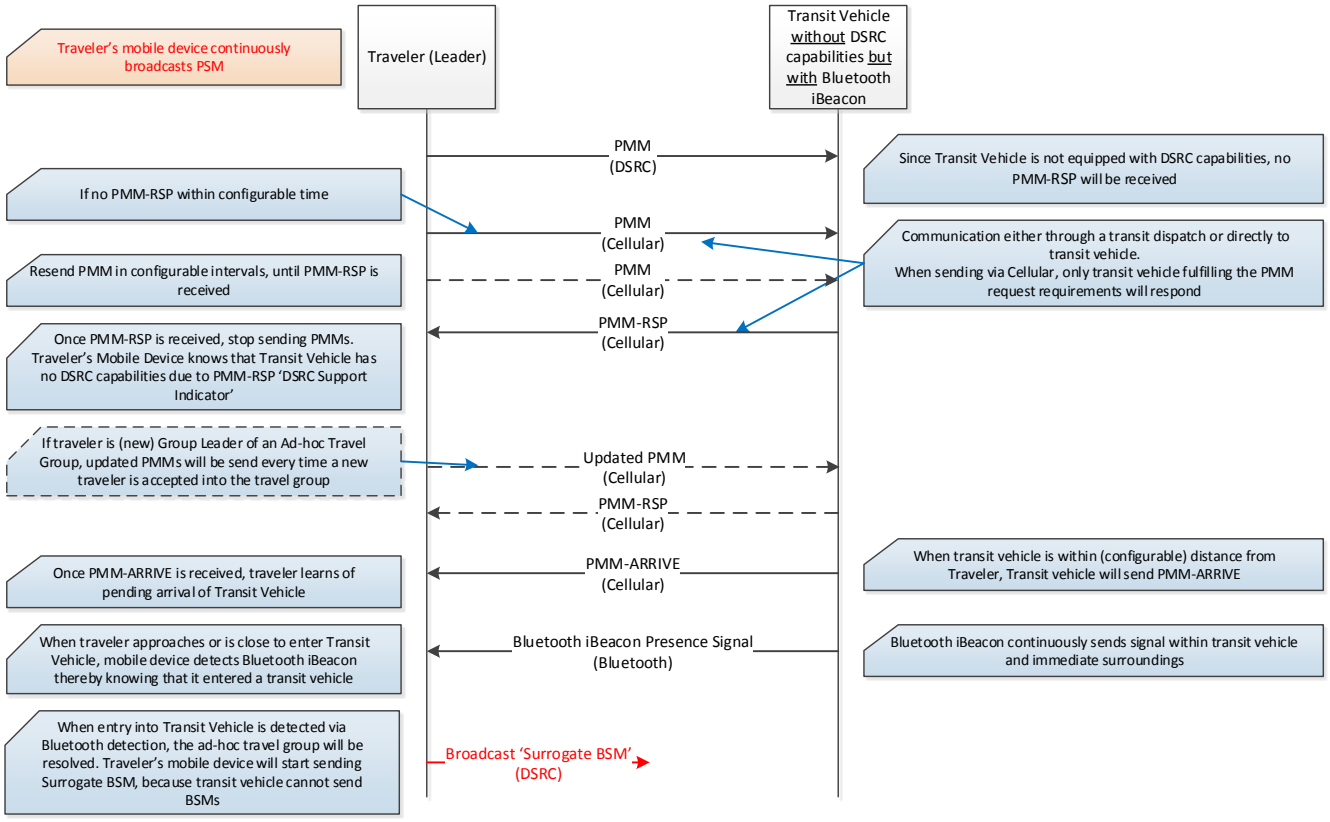
1. If the geographic location of the user entering the ride/travel request (PMM) information is outside of the range of a responding vehicle over DSRC (no PMM-RSP received via DSRC) and the Transit Stop is RSE-equipped, the mobile device will attempt to send the PMM to a Transit Stop RSE via DSRC. If the mobile device is not DSRC-equipped, the PMM could be communicated to the Transit Stop RSE via Wi-Fi Direct. The RSE transmits information to the

cloud infrastructure and ultimately to a transit vehicle (Note: this functionality is not included in the EPS).

2. If the transit stop is not RSE-equipped, the mobile device will attempt to send the PMM over cellular (3G or 4G/LTE depending on availability) and transmitted via the cloud infrastructure ultimately to a transit vehicle. The PMM could be sent via cellular from a home location as well. (Note: the ability to send a PMM via cellular at a location away from the Transit Stop is not included in the EPS).
   Note that the data could be sent to a transit dispatch center, which informs the approaching transit vehicle.
3. Once a mobile device sending a PMM is within DSRC range (PMM-RSP received via DSRC), the ride / travel request message will be sent over DSRC communications.
4. If a transit vehicle, which has DSRC equipment on-board, comes into DSRC range and receives a PMM, which indicates that the travel group is larger than the capacity, or has persons with mobility limitations that the vehicle cannot fulfill, the vehicle will send a PMM-RSP with availability information.
5. Should a mobile device again move outside of DSRC range, the ride / travel request message will be send over cellular. Devices not-equipped with DSRC would necessarily receive this message through the Transit Stop RSE.
6. A transit vehicle having received a ride / transit request message and capable to fulfill the (new or updated) ride / travel request requirements will create and send a PMM response (PMM RSP) message over either cellular (if outside of DSRC range, or no DSRC capability) or DSRC (if within DSRC range).
7. The travel group leader mobile device that sent the PMM will receive the PMM RSP over either cellular or DSRC (if in range) and, in response, will cease to send PMMs.
8. Should additional mobile devices with the same itinerary (same coordination request message contents) join the travel group, the travel group team leader mobile device will send updated PMMs with the new number of travel group members to the approaching transit vehicle.
9. When the transit vehicle comes into the configurable DSRC range, it will send an arrival message (PMM-ARRIVE) to the travel group leader mobile device.
10. When the transit vehicle has stopped to pick up the travel group members, a mobile device will sense the Bluetooth iBeacon's signal. After a configurable time, it is assumed that the travel group members have entered the vehicle, which leads to the following actions:
    - The travel group will disband and no further joined actions will be executed.
    - The travel group member's mobile devices will cease to send PSM (sending the safety message will be up to the vehicle's DSRC equipment).
11. During the whole process, the vehicle continues to send the vehicle-specific BSM.
12. When the vehicle approaches the alighting location for the traveler, the vehicle will issue an Alight Vehicle Message to the pedestrian (Note: this functionality is not included in the EPS).

Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle

The following UML diagram defines the data exchange sequence for requesting and entering a transit vehicle not equipped with DSRC equipment, which is succeeded by a description.



Source: Battelle

Figure 7. UML Diagram – Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle

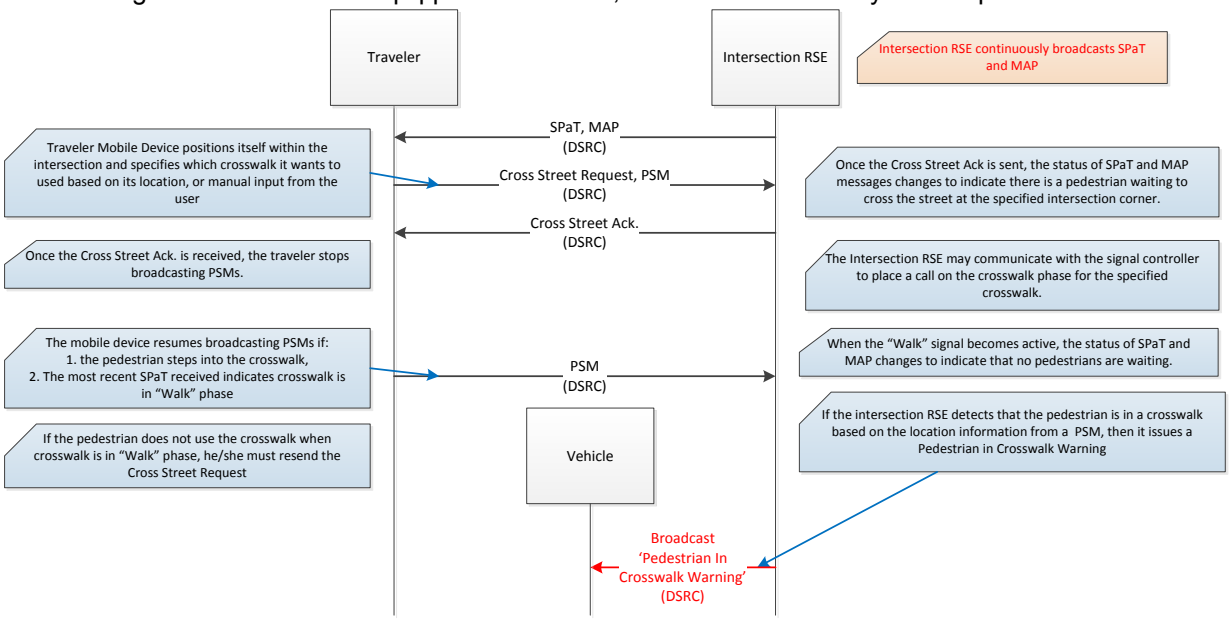
The data exchange sequence shown above is similar to the data exchange sequence shown in Figure 5, with the difference that the approaching transit vehicles does not include DSRC equipment on-board but it does include a Bluetooth iBeacon to allow a mobile device to whether it entered a vehicle.. The steps shown in the above UML Diagram are explained in the following paragraphs:

1. The mobile device sends a PMM over DSRC but receives no response from the Light Duty vehicle.
2. After a configurable duration has passed, the mobile device assumes that there is no Light Duty vehicle with DSRC capabilities is nearby. In response, the mobile device sends its PMM request via cellular and continues to send the PMM request until a response from a transit vehicle is received via cellular.
   Note: again, the PMM message over cellular could have first been sent via a dispatch center to the Light Duty vehicle.
3. If the geographic location of the user entering the ride/travel request (PMM) information is outside of range the range of DSRC (no PMM RSP received via DSRC), the information will be send over cellular (3G or 4G/LTE depending on availability) and transmitted via the cloud infrastructure ultimately to a passenger-transporting vehicle.
   Note that the data could be sent to a transit dispatch center, which informs the approaching passenger-transporting vehicle.

4. A vehicle having received a ride / transit request message and capable to fulfill the (new or updated) ride / travel request requirements will create and send a PMM response (PMM RSP) message over cellular.
5. The travel group leader mobile device that sent the PMM will receive the PMM-RSP over cellular and, in response, will cease to send PMMs.
6. Should additional mobile devices with the same itinerary (same coordination request message contents) join the travel group, the travel group team leader mobile device will send updated PMMs with the new number of travel group members to the approaching vehicle.
7. When the vehicle comes into the configurable distance range (calculated by the vehicle application based on comparing the traveler request with its own position), the vehicle will send an arrival message (PMM-ARRIVE) to the travel group leader mobile device.
8. When the transit vehicle has stopped to pick up the travel group members, a mobile device will sense the Bluetooth iBeacon's signal. After a configurable time, it is assumed that the travel group members have entered the vehicle, which leads to the following actions:
    - The travel group will disband and no further joined actions will be executed.
    - The travel group member's mobile devices will cease to send PSMs (which will now be send by the first mobile device having stopped sending PSMs and realizing that no BSMs are being sent).
9. After the traveler(s) enter the vehicle and knowing that the vehicle is not equipped with DSRC capabilities, the mobile device of the first mobile device, having stopped sending PSMs and realizing that no BSM is being sent, generates and starts to send a Surrogate BSM, which mimics a vehicle's BSM message contents but with an indicator that this is not a real BSM. *For example, the mobile device cannot know anything about a vehicles steering wheel angle or the vehicle's size (width and length)* (Note: this functionality is not included in the EPS).

Requesting and Crossing a Street at an RSE-equipped Intersection

The following UML diagram defines the data exchange sequence for requesting to use a crosswalk and crossing a street at an RSE-equipped intersection, which is succeeded by a description.



Source: Battelle

Figure 8. UML Diagram – Requesting and Crossing a Street at an RSE-equipped Intersection

The data exchange sequence shown above involves the coordination between a pedestrian mobile device and a RSE-equipped intersection. The pedestrian is able to receive information about the intersection's layout as well as its phasing and timing plan. The pedestrian is able to tell the Intersection RSE which crosswalk he/she would like to use. The Intersection RSE sends an acknowledgement to the pedestrian, so that they may stop broadcasting PSMs. The pedestrian resumes sending PSMs when they enter the crosswalk. The steps shown in the above UML Diagram are explained in the following paragraphs:

1. An intersection broadcasts SPaT and MAP messages via DSRC. A pedestrian's mobile device receives these messages and is able to position itself within the intersection.
2. The pedestrian needs to cross the street at the intersection. The pedestrian send a Cross Street Request (containing a unique ID, the intersection corner of the pedestrian, and the crosswalk he/she wishes to use.
3. Once receiving the Cross Street Request, the Intersection RSE issues a Cross Street Acknowledgement containing the same unique ID. The Intersection RSE revises its SPaT and MAP messages accordingly, to let vehicles in its vicinity know that there is a pedestrian waiting on that corner of the intersection.
4. Once the mobile device receives the acknowledgement, it stops broadcasting PSMs. It is important to note that the pedestrian is still on the street corner at this point.
5. The mobile device continuously receives SPaT messages, and at some point, begins to cross the street. The mobile device nearly immediately resumes broadcasting PSMs in two instances:
    a. If the crosswalk the pedestrian wishes to use is the "Walk" phase.
    b. If the pedestrian's mobile device has detected that it is in the crosswalk.
6. Once the crosswalk is in the "Walk" phase, the Intersection RSE changes the status of its SPaT and MAP messages to indicate that there are no longer pedestrians on that corner.
7. Based on the location of the pedestrian, the Intersection RSE broadcasts a Pedestrian In Crosswalk Warning.

3.6 Performance Requirements

The performance requirements for the Experimental Prototype System are defined in the next table.

Again, as with the Functional Requirements, the following performance requirements are a larger set of requirements than those required for use within the Experimental Prototype System (EPS) demonstration tests. A 'Y' indication means that the corresponding requirment is part of this task order's demonstration tests, while an 'N' indicates that the corresponding requirement is not.

Table 4: Performance Requirements Table

PR ID	Performance Requirement Title	Performance Requirement Description	EPS Req
PR 1.0 Mobile Device Performance Requirements			
PR 1.01	Mobile device lane level positioning accuracy	A mobile device shall detect the accuracy of its position. *Note: In order for applications to work as intended, It is expected that position can be estimated with Lane Level Positioning Accuracy, defined to be 30 cm.*	Y
PR 1.02	Mobile device unsafe zone detection accuracy	A mobile device shall detect whether the pedestrian is in an "unsafe zone". *NOTES:* - *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*	Y
PR 1.03	Mobile device path history (20 secs)	A mobile device shall detect and record its path history for the last 20 seconds.	Y
PR 1.04	Mobile device path prediction (5 secs)	A mobile device shall predict and record its path for the next 5 seconds.	Y
PR 1.05	Mobile device - Determining Vehicle Size and Length	A mobile device shall determine the length and width of the vehicle in which it is located. *Note: this is not currently technically possible (except if the vehicle sends this information), but it is a requirement.*	N
PR 1.07	Mobile Device RF Performance Requirements	A mobile device shall conform to RF performance requirements for DSRC communications as outlined in SAE 2945-1, Clause 6.4 *Note: this Requirement is for any message sent/received via DSRC.*	Y
PR 1.11	Capture 90% of Coordination Messages sent over Wi-Fi-Direct	A mobile device shall receive and capture 90% of coordination messages transmitted over Wi-Fi-Direct communication media at a distance of 10 meters or less. *Note: It is expected that 10 meters is the maximum distance at which messages sent via Wi-Fi-Direct will need to be sent to support travel coordination applications.*	Y
PR 1.15	Display Message Content within 0.1 seconds after receipt of message content	A mobile device shall display message contents, whose information is to be displayed to the user, within 0.1 seconds after the message has been received by the mobile device.	Y
PR 1.16	Detecting when entering Light Duty vehicle within 10 seconds of entering 90% of times	A mobile device shall be able to detect within 10 seconds of entering a Light Duty vehicle 90% of the time.	Y
PR 1.17	Detecting when entering Light Duty vehicle before vehicle has traveled 3 meters 90% of times	A mobile device shall be able to detect the entering of a Light Duty vehicle before the vehicle has traveled 3 meters 90% of the time.	Y
PR 1.18	Detecting when exiting Light Duty vehicle within 10 seconds of entering 90% of times	A mobile device shall be able to detect within 10 seconds of exiting a Light Duty vehicle 90% of the time.	Y
PR 1.19	Detecting when exiting Light Duty vehicle before vehicle has traveled 3 meters 90% of times	A mobile device shall be able to detect the exiting of a Light Duty vehicle before the vehicle has traveled 3 meters 90% of the time.	Y

PR 1.20	Detecting when entering transit vehicle within 10 seconds of entering 90% of times	A mobile device shall be able to detect within 10 seconds of entering a transit vehicle 90% of the time.	Y
PR 1.21	Detecting when entering transit vehicle before vehicle has traveled 3 meters 90% of times	A mobile device shall be able to detect the entering of a transit vehicle before the vehicle has traveled 3 meters 90% of the time.	Y
PR 1.22	Capture 90% of Alight Vehicle Messages sent over Wi-Fi-Direct	A mobile device shall receive and capture 90% of Alight Vehicle messages transmitted by a vehicle that the mobile device is inside of over Wi-Fi-Direct communication media.	N
PR 1.23	Detecting when exiting transit vehicle within 10 seconds of entering 90% of times	A mobile device shall be able to detect within 10 seconds of exiting a transit vehicle 90% of the time.	Y
PR 1.24	Detecting when exiting transit vehicle before vehicle has traveled 3 meters 90% of times	A mobile device shall be able to detect the exiting of a transit vehicle before the vehicle has traveled 3 meters 90% of the time.	Y
PR 1.25	Detecting at which intersection corner 90% of times.	A mobile device shall be able to detect which corner of an intersection it is currently located 90% of the time.	N
PR 1.26	Detecting when entering a crosswalk 99% of times.	A mobile device shall be able to detect when it is in a crosswalk within 1 second of entering the crosswalk 99% of the time.	N
PR 1.27	False Enter Crosswalk Detection rate in less than 5% of street crossing instances.	A mobile device shall falsely position itself in a crosswalk in fewer than 5% of crossing instances with the pedestrian waits to cross the street in a location no less than 3 meters from any curb.	N
PR 2.0 Vehicle Performance Requirements			
PR 2.01	Vehicle RF Performance Requirements	A vehicle shall conform to RF performance requirements for DSRC communications as outlined in SAE 2945-1, Clause 6.4 *Note: This Requirement is for any message sent/received via DSRC.*	Y
PR 2.02	Vehicle lane level positioning accuracy	A vehicle shall detect the accuracy of its position. *Note: In order for applications to work as intended, It is expected that position can be estimated with Lane Level Positioning Accuracy, defined to be 30 cm.*	Y
PR 3.0 Transit Stop RSE Performance Requirements			
PR 3.01	Transit Stop RSE RF Performance Requirements	A Transit Stop RSE shall conform to RF performance requirements for DSRC communications as outlined in SAE 2945-1, Clause 6.4 *Note: This Requirement is for any message sent/received via DSRC.*	Y
PR 3.02	Protocol Translator	A Transit Stop RSE shall act as a protocol translator. Receiving PMMs via DSRC or Wi-Fi Direct, the RSE must be able to receive the message and translate into a format which can be received and understood by the cloud infrastructure and any entities that may access the cloud infrastructure.	N
PR 3.03	Relay Messages between Travelers and Cloud Service	A Transit Stop RSE shall relay PMMs from travelers to the cloud infrastructure, and relay PMM-RSPs from the cloud infrastructure to travelers.	N
PR 3.03.01	Relay Messages between Travelers and a TMC (or other transportation management agency)	A Transit Stop RSE shall relay PMMs from travelers to the cloud infrastructure, which can be accessed by a TMC or other transportation management agency. *Note: For the EPS, this will be demonstrated by locally saving messages received by the Transit Stop RSE.*	N

PR 3.04	Communications Media – DSRC	A Transit Stop RSE shall send any messages to a traveler via DSRC if the traveler sent messages to the Transit Stop RSE via DSRC.	N
PR 3.05	Communications Media – Wi-Fi Direct	A Transit Stop RSE shall send any messages to a traveler via Wi-Fi Direct if the traveler sent messages to the Transit Stop RSE via Wi-Fi Direct.	N
PR 4.0 Intersection RSE Performance Requirements			
PR 4.01	Intersection RSE RF Performance Requirements	An Intersection RSE shall conform to RF performance requirements for DSRC communications as outlined in SAE 2945-1, Clause 6.4 *Note: This Requirement is for any message sent/received via DSRC.*	Y
PR 4.02	Protocol Translator	An Intersection RSE must be able to translate Request to Cross Street Messages received into a format that can be received and understood by the signal controller.	N
PR 4.03	Send Request to Cross Street Messages to Cloud Service	An Intersection RSE shall relay Request to Cross Street Messages from travelers to the cloud infrastructure.	N
PR 4.03.01	Relay Messages between Travelers and a TMC (or other transportation management agency)	An Intersection RSE shall relay Request to Cross Street Messages from travelers to the cloud infrastructure, which can be accessed by a TMC or other transportation management agency. *Note: For the EPS, this will be demonstrated by locally saving messages received by the Intersection RSE.*	N
PR 5.0 Transmission Interference Performance Requirements			
PR 5.01	No interference between PSMs and BSMs	The transmission of PSMs shall not interfere with the transmissions of other PSM or with BSM messages.	Y
PR 5.02	No interference of PMMs with PSMs and BSMs	The transmission of PMMs shall not interfere with the transmissions of PSM or BSM messages.	Y
PR 5.03	No interference of Coordination Messages with PSMs and BSMs	The transmission of coordination messages for Ad-hoc Travel Groups shall not interfere with the transmissions of either PSM or BSM messages.	Y
PR 5.04	No interference of Coordination Messages with PMMs	The transmission of coordination messages for Ad-hoc Travel Groups shall not interfere with the transmissions of the different PMM message types.	Y
PR 5.05	No interference of Surrogate BSMs with PSMs and BSMs	The transmission of Surrogate BSMs shall not interfere with the transmissions of PSM or BSM messages.	N
PR 5.06	No interference of Coordination Messages with Coordination Messages from another ad-hoc travel group	The transmission of coordination messages from an Ad-hoc Travel Group shall not interfere with the transmissions of coordination messages from another Ad-hoc Travel Group.	Y
PR 5.07	No interference of Coordination Messages with Coordination Messages from several other ad-hoc travel groups	The transmission of coordination messages from an Ad-hoc Travel Group shall not interfere with the transmissions of coordination messages from other Ad-hoc Travel Groups.	Y

Source: Battelle

3.7 Security Requirements

No special security requirements beyond those required as part of the utilized communications protocols are required. The Security and Credentials Management System (SCMS) (Version 2, March 2016) is expected to be used in conjunction with future data exchange over DSRC, and might then be

used as part of this project, if it is available at the time the EPS is deployed. Theoretically, the SCMS is not needed to fulfill the majority of requirements nor is it necessary to answer the foundational research questions at the core of this project. The Security Requirements Table provides a high-level outline of security requirements that will be needed for a full-scale deployment – additional detailed requirements will need to be developed for these deployments in the future.

Again, as with the Functional Requirements, the following security requirements are a larger set of requirements than those required for use within the Experimental Prototype System (EPS) demonstration tests. A 'Y' indication means that the corresponding requirment is part of this task order's demonstration tests, while an 'N' indicates that the corresponding requirement is not.

Table 5: Security Requirements Table

SR ID	Security Requirement Title	Security Requirement Description	EPS Req
SR 1.0 DSRC Security Requirements			
SR 1.01	Interface mobile devices with SCMS	The DSRC radios of the mobile devices used in the EPS system should interface with the U.S. DOT provided SCMS for security key provisioning and management.	N
SR 1.02	Interface vehicles with SCMS	The DSRC radios within the vehicles used in the EPS system should interface with the U.S. DOT provided SCMS for security key provisioning and management.	N
SR 1.03	Interface RSEs with SCMS	The DSRC radios within the roadside receivers used in the EPS system should interface with the U.S. DOT provided SCMS for security key provisioning and management.	N
SR 1.04	Comply with SAE Guidance Standards	The DSRC radios within the mobile devices, vehicles, and roadside equipment units shall comply with the relevant SAE J2945-1 requirements, which references other security-related standards. For example, IEEE 1602.2 is referenced in J2945-1, Clause 6.5.2 - BSM Signing. Additionally, the use of SCMS is referenced in J2945-1, Clause 6.6 – Security Management. *NOTE: see Section 2.1 for the versions of the references standards that are applicable at the time this document was submitted.*	Y

Source: Battelle

Note: The above requirements are objective (should) requirements due to the likelihood that the SCMS will not be available in time for EPS system deployment.

3.8 Data Requirements

The data requirements for the Experimental Prototype System are defined in the next table. Again, as with the Functional Requirements, the following data requirements are a larger set of requirements than those required for use within the Experimental Prototype System (EPS) demonstration tests. A 'Y' indication means that the corresponding requirment is part of this task order's demonstration tests, while an 'N' indicates that the corresponding requirement is not.

Table 6: Data Requirements Table

DR ID	Data Requirement Title	Data Requirement Description	EPS
DR 1.0 Mobile Device Data Requirements			
DR 1.01	Store all mobile device data transmissions for the duration of test plan execution	A mobile device shall be able to store all data exchanges / data transmissions regardless of the communications media sent during the execution of the entire test plan.	Y
DR 1.02	Store all mobile device screen displays for the duration of test plan execution	A mobile device shall be able to store all user-facing displays on the mobile device screen sent during the execution of the entire test plan.	Y
DR 2.0 Vehicle Data Requirements			
DR 2.01	Store all vehicle data transmissions for the duration of test plan execution	A vehicle shall be able to store all data exchanges / data transmissions regardless of the communications media sent during the execution of the entire test plan.	Y
DR 2.02	Store all vehicle screen displays for the duration of test plan execution	A vehicle shall be able to store all user-facing displays on the vehicle display screen sent during the execution of the entire test plan.	Y
DR 3.0 Roadside Equipment Data Requirements			
DR 3.01	Store all roadside equipment DSRC data transmissions	A roadside device (both intersection and transit stop-based) shall be able to store all DSRC data exchanges / data transmissions. *Note: The storage device should be able to store all data received via DSRC during a small-scale demonstration lasting less than 3 days.*	Y
DR 3.02	Offload/Download Data Stored in RSE	It must be possible to offload / download the stored data via manual or automatic local or remote download mechanisms.	N
DR 4.0 Cloud Infrastructure Data Requirements			
DR 4.01	Store all roadside equipment cellular data transmissions for the duration of test plan execution	A device connected to the cloud infrastructure shall be able to store all cellular data exchanges / data transmissions sent during the execution of the entire test plan.	Y

Source: Battelle

3.9 Reliability Requirements

The reliability requirements for the Experimental Prototype System are defined in the next table. Again, as with the Functional Requirements, the following reliability requirements are a larger set of requirements than those required for use within the Experimental Prototype System (EPS) demonstration tests. A 'Y' indication means that the corresponding requirment is part of this task order's demonstration tests, while an 'N' indicates that the corresponding requirement is not.

Table 7: Reliability Requirements Table

RR ID	Reliability Requirement Title	Reliability Requirement Description	EPS Req
RR 1.0 Mobile Device Reliability Requirements			
RR 1.01	Mobile Device operates for at least 3 hours	A mobile device shall be able to operate for at least 3 hours before needing to recharge.	Y
RR 1.02	MDEA runs without need to restart	The MDEA installed and executed on a mobile device shall run without the need for restart/reboot for the duration of a complete test procedure.	Y
RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	The DSRC infrastructure shall be available and operational without any interruptions of coverage within the test facility for the duration of the entire test plan.	Y
RR 1.04	Cellular infrastructure available for entire test period without interruptions or lack of coverage at test facility	The cellular infrastructure shall be available and operational without any interruptions of coverage within the test facility for the duration of the entire test plan.	Y
RR 2.0 Vehicle Reliability Requirements			
RR 2.01	VEA operates for at least 3 hours	A VEA installed and executed on in-vehicle equipment shall be able to operate for at least 3 hours before needing to recharge. *Notes: this is a non-issue if the in-vehicle equipment is powered by the battery of the vehicle, but important if powered by external, on-equipment battery.*	Y
RR 2.02	VEA runs without need to restart	The VEA installed and executed on a mobile device shall run without the need for restart/reboot for the duration of a complete test procedure.	Y
RR 2.03	Bluetooth iBeacon operates for at least 6 hours	A Bluetooth iBeacon device installed on a vehicle, used for the purpose of allowing a mobile device sense when it is inside of the vehicle, shall be able to operate for at least 6 hours without the need of recharging. *Note: this is a non-issue if the Bluetooth equipment is powered by the battery of the vehicle, but important if powered by external, on-equipment battery.*	Y
RR 3.0 Roadside Equipment Reliability Requirements			
RR 3.01	Roadside equipment operates for at least 3 hours	Roadside equipment (both intersection and transit stop-based) shall be able to operate for at least 3 hours before needing to recharge. *Note: this is a non-issue if the roadside equipment is powered by AC power, but important if powered by external, on-equipment battery.*	Y
RR 3.02	Roadside equipment application runs without need to restart	The application installed and executed on roadside equipment (both intersection and transit stop-based) shall run without the need for restart/reboot for the duration of a complete test procedure.	Y
RR 4.0 Cloud Infrastructure Reliability Requirements			
RR 4.01	Cloud infrastructure operates for entire test plan duration	The cloud infrastructure shall be able to operate without needing to restart or recharge.	Y
RR 4.02	Cloud infrastructure runs without need to restart	The cloud infrastructure shall run without the need for restart/reboot for the duration of a complete test procedure.	Y
RR 4.03	Cellular infrastructure available for entire test period without interruptions or lack of coverage at test facility	The cloud infrastructure shall be available and operational without any interruptions or coverage within the test facility of the entire test plan.	Y

Source: Battelle

3.10 Needs to Requirements Traceability Matrix

The following matrix shows the mapping of the identified user needs to the system requirements. The columns in the matrix are the User Need ID and User Need columns, FR ID and Functional Requirement columns and the Additional Specifications column, with the following definitions for each:

a) User Need ID - the unique number assigned to the user need statement. The user needs are defined in the ConOps.
b) User Need – the user need title associated with the user need as defined in the ConOps.
c) Req ID – the unique number assigned to a requirement statement as defined in the previous sections of this document. The references within the matrix traces from user needs to these requirements.
d) Requirement – the short requirements title associated with the requirement as defined in the sections above.
e) Conformance – Indicates if the implementation is mandatory or optional. It is up to the purchase / Technical Specifications used in Requests for Proposals (RFPs) to specify
g) Additional Specifications - identifies other requirements that must be satisfied, including user selectable range values. The "Additional Specifications" column within these system requirements are used to provide additional notes and requirements for the system.

Table 8: User Needs to Requirements Traceability Matrix

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
UN 1.0	Driver and Pedestrian Warning / Alert Reception Needs			M	
UN 1.01	Driver Advisory of Pedestrians in Area			M	
		FR 1.01	Broadcasting PSMs	M	
		FR 1.02	PSM Broadcasting Frequency	M	
		FR 11.01	Displaying Advisory within Vehicle	M	
		SIR 1.01	PSM Broadcasting Frequency	M	
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Pedestrians	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.07	PSM Radius of Protection expandable	M	
		SIR 1.08	PSM Path History	O	
		SIR 1.09	PSM Path Prediction	O	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2735:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	
		PR 1.03	Mobile device path history (20 secs)	O	
		PR 1.04	Mobile device path prediction (5 secs)	O	
		PR 2.02	Vehicle lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 2.01	Store all vehicle data transmissions for the duration of test plan execution	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		RR 2.01	VEA operates for at least 3 hours	M	
		RR 2.02	VEA runs without need to restart	M	
UN 1.02	Driver Alerts of Pedestrians in Unsafe Zone			M	
		FR 1.01	Broadcasting PSMs	M	
		FR 1.02	PSM Broadcasting Frequency	M	
		FR 1.06	Sending PSMs when in unsafe zone	M	
		FR 11.02	Displaying Alert within Vehicle	M	
		SIR 1.01	PSM Broadcasting Frequency	M	
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Peds	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.08	PSM Path History	O	
		SIR 1.09	PSM Path Prediction	O	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2735:2016 if MSGs and Des fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	
		PR 2.01	Vehicle RF Performance Requirements	M	
		PR 2.02	Vehicle lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 2.01	Store all vehicle data transmissions for the duration of test plan execution	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
		RR 2.01	VEA operates for at least 3 hours	M	
		RR 2.02	VEA runs without need to restart	M	
UN 1.03	Driver Warning of Pedestrians in travel lane			M	
		FR 1.01	Broadcasting PSMs	M	
		FR 1.02	PSM Broadcasting Frequency	M	
		FR 10.03	Displaying Warning within Vehicle	M	
		SIR 1.01	PSM Broadcasting Frequency	M	
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Peds	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.08	PSM Path History	O	
		SIR 1.09	PSM Path Prediction	O	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2735:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	
		PR 2.01	Vehicle RF Performance Requirements	M	
		PR 2.02	Vehicle lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 2.01	Store all vehicle data transmissions for the duration of test plan execution	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
		RR 2.01	VEA operates for at least 3 hours	M	
		RR 2.02	VEA runs without need to restart	M	
				M	
UN 1.05	Driver Warning of Pedestrian in Crosswalk without permissive Pedestrian Indication			M	
		FR 1.02	PSM Broadcasting Frequency	M	
		FR 10.03	Displaying Warning within Vehicle	M	
		SIR 1.01	PSM Broadcasting Frequency	M	
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Peds	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.08	PSM Path History	O	
		SIR 1.09	PSM Path Prediction	O	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2735:2016 if MSGs and DEs fulfill requirements	M	
		FR 11.07	Display Pedestrian in Crosswalk Warning within Vehicle	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	
		DR 2.01	Store all vehicle data transmissions for the duration of test plan execution	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
		RR 2.01	VEA operates for at least 3 hours	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		RR 2.02	VEA runs without need to restart	M	
UN 1.11	Pedestrian Advisory of vehicles approaching			M	
		FR 4.01	Generating BSMs	M	
		FR 4.01.01	Generating BSM Content	M	
		FR 4.02	Broadcasting BSMs	M	
		FR 4.03	Receiving BSMs	M	
		FR 11.04	Displaying Advisory within Mobile device	M	
		SIR 7.01	BSM Location (lat/long/elev)	M	
		SIR 7.02	BSM Speed	M	
		SIR 7.03	BSM Heading	M	
		SIR 7.04	BSM Vehicle Size	M	
		SIR 7.05	BSM Vehicle Travel Lane	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2736:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 1.01	Store all mobile device data transmissions and screen displays for the duration of test plan execution	M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
				M	
UN 1.12	Pedestrian Alert of approaching vehicles when in unsafe zone			M	
		FR 4.01	Generating BSMs	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 4.01.01	Generating BSM Content	M	
		FR 4.02	Broadcasting BSMs	M	
		FR 4.03	Receiving BSMs	M	
		FR 10.06	Displaying Warning within Mobile device	M	
		SIR 6.01	Surrogate BSM Location (lat/long/elev)	M	
		SIR 6.02	Surrogate BSM Speed	M	
		SIR 6.03	Surrogate BSM Heading	M	
		SIR 6.04	Surrogate BSM Indicator	M	
		SIR 7.01	BSM Location (lat/long/elev)	M	
		SIR 7.02	BSM Speed	M	
		SIR 7.03	BSM Heading	M	
		SIR 7.04	BSM Vehicle Size	M	
		SIR 7.05	BSM Vehicle Travel Lane	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2736:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 1.01	Store all mobile device data transmissions and screen displays for the duration of test plan execution	M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
				M	
UN 1.13	Mobile Device user Warning of vehicle approaching when in Travel Lane			M	
		FR 4.01	Generating BSMs	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 4.01.01	Generating BSM Content	M	
		FR 4.02	Broadcasting BSMs	M	
		FR 4.03	Receiving BSMs	M	
		FR 11.05	Displaying Warning within Mobile device	M	
		SIR 7.01	BSM Location (lat/long/elev)	M	
		SIR 7.02	BSM Speed	M	
		SIR 7.03	BSM Heading	M	
		SIR 7.04	BSM Vehicle Size	M	
		SIR 7.05	BSM Vehicle Travel Lane	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2736:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 1.01	Store all mobile device data transmissions and screen displays for the duration of test plan execution	M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
UN 1.14	Warning of Pedestrian when entering a signalized crosswalk during Don't Walk times			M	
		FR 4.01	Generating BSMs	M	
		FR 4.01.01	Generating BSM Content	M	
		FR 4.02	Broadcasting BSMs	M	
		FR 4.03	Receiving BSMs	M	
		FR 11.08	Display Pedestrian in Crosswalk Warning within Mobile Device	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 7.01	BSM Location (lat/long/elev)	M	
		SIR 7.02	BSM Speed	M	
		SIR 7.03	BSM Heading	M	
		SIR 7.04	BSM Vehicle Size	M	
		SIR 7.05	BSM Vehicle Travel Lane	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2736:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		DR 1.01	Store all mobile device data transmissions and screen displays for the duration of test plan execution	M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
UN 2.0	Mobile Device and In-Vehicle Device Warning / Alert Generation Needs			M	
UN 2.01	Driver Receipt of Advisories, Alerts, and Warnings independent of device placement on person			M	
		FR 11.01	Displaying Advisory within Vehicle	M	
		FR 11.02	Displaying Alert within Vehicle		
		FR 11.03	Displaying Warning within Vehicle		
		FR 11.07	Display Pedestrian in Crosswalk Warning within Vehicle		
UN 2.02	Pedestrian Receipt of Advisories, Alerts, and Warnings independent of device placement on person			M	
		FR 11.04	Displaying Advisory within Mobile Device	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 11.05	Displaying Alert within Mobile Device		
		FR 11.06	Displaying Warning within Mobile Device		
		FR 11.08	Display Pedestrian in Crosswalk Warning within Mobile Device		
				M	
UN 2.03	Driver Receipt of Advisories, Alerts, and Warnings independent of device placement on wheelchair			M	
		FR 11.01	Displaying Advisory within Vehicle	M	
		FR 11.02	Displaying Alert within Vehicle		
		FR 11.03	Displaying Warning within Vehicle		
		FR 11.07	Display Pedestrian in Crosswalk Warning within Vehicle		
				M	
UN 2.04	Wheelchair-bound Person Receipt of Advisories, Alerts, and Warnings independent on device placement on wheelchair			M	
		FR 11.05	Displaying Advisory within Mobile Device	M	
		FR 11.05	Displaying Alert within Mobile Device	M	
		FR 11.06	Displaying Warning within Mobile Device	M	
		FR 11.08	Display Pedestrian in Crosswalk Warning within Mobile Device	M	
UN 2.05	Pedestrian in Crosswalk Detection				
		FR 1.06	Sending PSMs when in unsafe zone	M	
		FR 11.07	Display Pedestrian in Crosswalk Warning within Vehicle	M	
		SIR 9.01	SPaT Broadcasting Frequency	M	
		SIR 9.02	Status of Signal Controller	M	
		FR 1.01	Broadcasting PSMs	M	
		FR 1.02	PSM Broadcasting Frequency	M	
		FR 10.03	Displaying Warning within Vehicle	M	
		SIR 1.01	PSM Broadcasting Frequency	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Peds	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.08	PSM Path History	M	
		SIR 1.09	PSM Path Prediction	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2735:2016 if MSGs and DEs fulfill requirements	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	
UN 3.0	Mobile Device in Vehicle Location Detection and Accuracy Needs			M	
UN 3.01	Detection of Passenger within Light Duty Vehicle			M	
		FR 6.01	Detecting when entering DSRC equipped Light Duty vehicle	M	
		FR 6.02	Detecting when entering non-DSRC equipped Light Duty vehicle	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	
		PR 1.16	Detecting when entering Light Duty vehicle within 10 seconds of entering 90% of times	M	
		PR 1.17	Detecting when entering Light Duty vehicle before vehicle has traveled 3 meters 90% of times	M	
				M	
UN 3.02	Detection of Passenger Alighting Light Duty Vehicle			M	
		FR 6.03	Detecting when exiting DSRC equipped Light Duty vehicle	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 6.04	Detecting when exiting non-DSRC equipped Light Duty vehicle	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	
		PR 1.18	Detecting when exiting Light Duty vehicle within 10 seconds of entering 90% of times	M	
		PR 1.19	Detecting when exiting Light Duty vehicle before vehicle has traveled 3 meters 90% of times	M	
				M	
UN 3.03	Detection of Passenger within Transit Vehicle			M	
		FR 7.01	Detecting when entering DSRC equipped transit vehicle	M	
		FR 7.02	Detecting when entering non-DSRC equipped transit vehicle	M	
		FR 7.03	Detecting presence of Bluethooth connectivity in transit vehicle	M	
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	
		PR 1.20	Detecting when entering transit vehicle within 10 seconds of entering 90% of times	M	
		PR 1.21	Detecting when entering transit vehicle before vehicle has traveled 3 meters 90% of times	M	
				M	
UN 3.04	Detection of Passenger Alighting Transit Vehicle			M	
		FR 7.04	Detecting when exiting DSRC equipped transit vehicle	M	
		FR 7.05	Detecting when exiting non-DSRC equipped transit vehicle	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	
		PR 1.22	Detecting when exiting transit vehicle within 10 seconds of entering 90% of times	M	
		PR 1.23	Detecting when exiting transit vehicle before vehicle has traveled 3 meters 90% of times	M	
				M	
UN 3.05	Location within Virtual Digital Intersection Map			M	
		FR 1.06	Sending PSMs when in unsafe zone	M	
		SIR 1.01	PSM Broadcasting Frequency	M	
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Peds	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.08	PSM Path History	O	
		SIR 1.09	PSM Path Prediction	O	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2735:2016 if MSGs and DEs fulfill requirements	M	
		FR 11.07	Display Pedestrian in Crosswalk Warning within Vehicle	M	
		FR 11.08	Display Pedestrian in Crosswalk Warning within Mobile Device	M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
UN 4.0	Mobile Device User / Vehicle Travel Coordination Needs			M	
UN 4.01	Send travel / ride request message			M	
		FR 2.01	Creating PMMs	M	
		FR 2.01.01	Creating PMM Content	M	
		FR 2.02	Sending PMMs	M	
		FR 2.03	Transmitting PMMs over various communications media	M	
		FR 2.11	Sending PMM at a-location outside of DSRC range	M	
		SIR 2.01	PMM Request ID	M	
		SIR 2.02	PMM Location (lat/long/elev)	M	
		SIR 2.03	PMM Number of Travelers	M	
		SIR 2.04	PMM Pickup Time	M	
		SIR 2.05	PMM Pickup Location	M	
		SIR 2.06	PMM Destination	M	
		SIR 2.07	PMM Mode of Transport	M	
		SIR 2.08	PMM Mobility Needs	M	
		SIR 2.09	PMM ETA Threshold	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
				M	
				M	
UN 4.02	Update travel / ride request message			M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 2.07	Updating a PMM	M	
		SIR 2.01	PMM Request ID	M	
		SIR 2.02	PMM Location (lat/long/elev)	M	
		SIR 2.03	PMM Number of Travelers	M	
		SIR 2.04	PMM Pickup Time	M	
		SIR 2.05	PMM Pickup Location	M	
		SIR 2.06	PMM Destination	M	
		SIR 2.07	PMM Mode of Transport	M	
		SIR 2.08	PMM Mobility Needs	M	
		SIR 2.09	PMM ETA Threshold	M	
		SIR 5.01	PMM-ARRIVE Request ID	M	
		SIR 5.02	PMM-ARRIVE Location (lat/long/elev)	M	
		SIR 5.03	PMM-ARRIVE ETA	M	
		SIR 5.04	PMM-ARRIVE Visible Vehicle ID	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
				M	
UN 4.03	Receive travel / ride request acknowledgement			M	
		FR 2.04	Receiving a PMM acknowledgement receipt via DSRC	M	
		FR 2.05	Receiving a PMM acknowledgement receipt via cellular		
		FR 2.06	Generating PMM Response content	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 2.09	Sending a PMM arrival message	M	
		FR 2.10	Receiving a PMM arrival message	M	
		SIR 3.01	PMM-RSP Request ID	M	
		SIR 3.02	PMM-RSP Location	M	
		SIR 3.03	PMM-RSP DSRC Support Indicator	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
				M	
UN 4.04	Stop sending travel / ride requests			M	
		FR 2.06	Manually cancelling a PMM	M	
		SIR 4.01	PMM-CANCEL Request ID	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
				M	
UN 4.05	Resume PSM broadcasting			M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 1.01	Broadcasting PSMs	M	
		FR 1.02	PSM Broadcasting Frequency	M	
		FR 1.03	Stop broadcasting PSMs	M	
		FR 1.04	Restarting broadcasting PSMs	M	
		SIR 1.01	PSM Broadcasting Frequency	M	
		SIR 1.02	PSM Location (lat/long/elev)	M	
		SIR 1.03	PSM Speed	M	
		SIR 1.04	PSM Heading	M	
		SIR 1.05	PSM Number of Peds	M	
		SIR 1.06	PSM Radius of Protection	M	
		SIR 1.08	PSM Path History	M	
		SIR 1.09	PSM Path Prediction	O	
		SIR 15.01	PSM over DSRC	M	
		SIR 20.03	Requesting and Entering a Ride with a DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		PR 5.01	No interference PSMs and BSMs	M	
UN 4.06	Cancelling travel / ride requests (PMM Cancel)			M	
		FR 2.08	Manually cancelling a PMM	M	
		FR 2.02	Sending PMMs	M	
		FR 2.03	Transmitting PMMs over various communications media	M	
		SIR 4.01	PMM-CANCEL Request ID		

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		PR 2.01	Vehicle RF Performance Requirements		
UN 4.11	Receive travel / ride request message				
		FR 2.02	Sending PMMs		
		FR 2.03	Transmitting PMMs over various communications media		
		FR 2.03.01	Transmitting PMMs – First Attempt – Communicate Directly with Vehicles in DSRC Range		
		FR 2.03.02	Transmitting PMM – Second Attempt – Communicate with RSE via DSRC		
		FR 2.03.03	Transmitting PMM – Third Attempt – Communicate with RSE via Wi-Fi Direct		
		FR 2.03.04	Transmitting PMM – Fourth Attempt – Communicate with Cloud Infrastructure via cellular		
		FR 2.04	Receiving a PMM acknowledgement receipt via DSRC		
		FR 2.05	Receiving a PMM acknowledgement receipt via cellular		
		SIR 2.01	PMM Request ID		
		SIR 2.02	PMM Location (lat/long/elev)		
		SIR 2.03	PMM Number of Travelers		
		SIR 2.04	PMM Pickup Time		
		SIR 2.05	PMM Pickup Location		
		SIR 2.06	PMM Destination		
		SIR 2.07	PMM Mode of Transport		
		SIR 2.08	PMM Mobility Needs		
		SIR 2.09	PMM ETA Threshold		
		PR 2.01	Vehicle RF Performance Requirements		
UN 4.12	Receive travel / ride request Update message				
		FR 2.07	Updating a PMM		
		FR 2.02	Sending PMMs		
		FR 2.03	Transmitting PMMs over various communications media		

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		FR 2.03.01	Transmitting PMMs – First Attempt – Communicate Directly with Vehicles in DSRC Range		
		FR 2.03.02	Transmitting PMM – Second Attempt – Communicate with RSE via DSRC		
		FR 2.03.03	Transmitting PMM – Third Attempt – Communicate with RSE via Wi-Fi Direct		
		FR 2.03.04	Transmitting PMM – Fourth Attempt – Communicate with Cloud Infrastructure via cellular		
		FR 2.04	Receiving a PMM acknowledgement receipt via DSRC		
		FR 2.05	Receiving a PMM acknowledgement receipt via cellular		
		SIR 2.01	PMM Request ID		
		SIR 2.02	PMM Location (lat/long/elev)		
		SIR 2.03	PMM Number of Travelers		
		SIR 2.04	PMM Pickup Time		
		SIR 2.05	PMM Pickup Location		
		SIR 2.06	PMM Destination		
		SIR 2.07	PMM Mode of Transport		
		SIR 2.08	PMM Mobility Needs		
		SIR 2.09	PMM ETA Threshold		
		PR 2.01	Vehicle RF Performance Requirements		
UN 4.13	Send travel / ride request acknowledgement			M	
		FR 2.03	Transmitting PMMs over various communications media	M	
		SIR 10.03	PMM, PMM-RSP, PMM-CANCEL over Cellular	M	
		SIR 3.01	PMM-RSP Request ID		
		SIR 3.02	PMM-RSP Location		
		SIR 3.03	PMM-RSP DSRC Support Indicator		
		PR 2.01	Vehicle RF Performance Requirements		
				M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
UN 4.15	Maintain communications when switching from one communications media to another			M	
		FR 2.03	Transmitting PMMs over various communications media	M	
		SIR 15.01	PSM over DSRC	M	
		SIR 15.02	PMM, PMM-RSP, PMM-CANCEL over DSRC	M	
		SIR 15.04	PMM, PMM-RSP, PMM-CANCEL over Cellular	M	
		SIR 15.05	PMM-ARRIVE over DSRC	M	
		SIR 15.06	Surrogate BSM over DSRC	M	
		SIR 15.07	BSM over DSRC	M	
		SIR 15.08	Any Coordination Message type over Wi-Fi-Direct	M	
		SIR 15.09	Mobile Device Detection via Bluetooth iBeacon	M	
		PR 5.01	No interference PSMs and BSMs	M	
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
		PR 5.03	No interference of Coordination Messages with PSMs and BSMs	M	
		PR 5.04	No interference of Coordination Messages with PMMs	M	
UN 4.20	Disembarkment Notification				
		FR 2.03	Transmitting PMMs over various communications media	M	
		FR 2.09	Sending a PMM arrival message	M	
		FR 2.10	Receiving a PMM arrival message	M	
		SIR 5.01	PMM-ARRIVE Request ID	M	
		SIR 5.02	PMM-ARRIVE Location (lat/long/elev)	M	
		SIR 5.03	PMM-ARRIVE ETA	M	
		SIR 5.04	PMM-ARRIVE Visible Vehicle ID	M	
		PR 1.07	Mobile Device RF Performance Requirements	M	
		PR 2.01	Vehicle RF Performance Requirements	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
UN 4.21	Receive signalized intersection information				
		SIR 9.01	SPaT Broadcasting Frequency	M	
		SIR 9.02	Status of Signal Controller	M	
		SIR 9.03	Prediction of Duration and Phases	M	
		SIR 10.01	MAP Broadcasting Frequency	M	
		SIR 10.02	Geographic information for Lanes in Intersection	M	
		SIR 10.03	Geographic information for Lanes for approaches	M	
		SIR 10.04	Types of Lanes	M	
UN 4.22	Request to use Crosswalk				
		FR 8.01	Detecting Intersection Corner Position	M	
		FR 8.02	Detecting Desired Crosswalk	M	
		FR 8.03	Detecting when entering a crosswalk	M	
		FR 9.01	Sending Intersection Crossing Request to Intersection	M	
		FR 9.02	Requesting the creation of an ad-hoc Intersection Crossing group	M	
		FR 9.03	Relaying Request to Cross Street Confirmation Message	M	
		FR 9.04	Determining an ad-hoc intersection crossing group leader	M	
		FR 9.05	Generating Intersection Crossing Group Coordination Message	M	
		FR 9.05.01	Generating Intersection Crossing Group Coordination Message Content	M	
		FR 9.06	Disbanding an ad-hoc intersection crossing group	M	
		SIR 12.01	Request ID	M	
		SIR 12.02	Intersection Corner Indicator	M	
		SIR 12.03	Crosswalk Indicator	M	
		SIR 12.04	Number of Pedestrians	M	
		SIR 12.05	Minimum Pedestrian Crossing Speed	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 13.01	Request ID	M	Request ID for acknowledgement message
UN 4.23	Receive Traveler information				
		SIR 14.01	Broadcasting Frequency	M	
UN 5.0	Mobile Device User Travel Group Coordination Needs			M	
UN 5.01	Creation of ad-hoc travel groups			M	
		FR 5.01	Sending mobile device itinerary to other mobile devices	M	
		FR 5.02	Requesting the creation of an ad-hoc travel group	M	
		FR 5.03	Generating Travel Group Coordination Confirmation Message	M	
		FR 5.03.01	Generating Travel Group Coordination Confirmation Message Content	M	
		FR 5.04	Determining an ad-hoc travel group travel leader	M	
		FR 5.05	Limiting travel group size	M	
		SIR 8.01	Coordination Message types using the same travel group ID	M	
		SIR 8.02	Coordination Request Message ID	M	
		SIR 8.03	Coordination Request Number of Requesters	M	
		SIR 8.04	Coordination Request Pickup Time	M	
		SIR 8.05	Coordination Request Pickup Location (lat/long/elev)	M	
		SIR 8.06	Coordination Request Destination (lat/long/elev)	M	
		SIR 8.07	Coordination Request Mode of Transport	M	
		SIR 8.10	Coordination Confirmation Message ID	M	
		SIR 8.11	Coordination Confirmation Travel Group ID	M	
		SIR 8.20	Coordination Heartbeat Message ID	M	
		SIR 8.21	Coordination Heartbeat Travel Group ID	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 15.08	Any Coordination Message type over Wi-Fi-Direct	M	
		SIR 20.01	Forming and Splitting of Travel Groups	M	
		SIR 20.02	Changing a Travel Group Leader	M	
		PR 1.11	Capture 90% of Coordination Messages sent over Wi-Fi-Direct	M	
		PR 5.03	No interference of Coordination Messages with PSMs and BSMs	M	
		PR 5.04	No interference of Coordination Messages with PMMs	M	
				M	
UN 5.02	Transmit ad-hoc travel group travel / ride requests			M	
		FR 2.02	Sending PMMs	M	
		FR 2.03	Transmitting PMMs over various communications media	M	
		FR 2.04	Receiving a PMM acknowledgement receipt	M	
		FR 2.06	Generating PMM Response content	M	
		FR 2.07	Updating a PMM	M	
		FR 2.11	Sending PMM at a-location outside of DSRC range	M	
		SIR 2.01	PMM Request ID	M	
		SIR 2.02	PMM Location (lat/long/elev)	M	
		SIR 2.03	PMM Number of Travelers	M	
		SIR 2.04	PMM Pickup Time	M	
		SIR 2.05	PMM Pickup Location	M	
		SIR 2.06	PMM Destination	M	
		SIR 2.07	PMM Mode of Transport	M	
		SIR 2.08	PMM Mobility Needs	M	
		SIR 2.09	PMM ETA Threshold	M	
		SIR 4.01	PMM-CANCEL Request ID	M	
		SIR 16.02	PMM, PMM-RSP, PMM-CANCEL over DSRC	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 10.03	PMM, PMM-RSP, PMM-CANCEL over Cellular	M	
		SIR 10.04	PMM-ARRIVE over DSRC	M	
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
		RR 2.01	VEA operates for at least 3 hours	M	
		RR 2.02	VEA runs without need to restart	M	
		RR 2.03	Bluetooth iBeacon operates for at least 3 hours	M	
UN 5.03	Receive travel / ride request acknowledgement while in travel group			M	
		FR 2.04	Receiving a PMM acknowledgement receipt via DSRC	M	
		FR 2.05	Receiving a PMM acknowledgement receipt via cellular	M	
		FR 2.06	Generating PMM Response content	M	
		SIR 3.01	PMM-RSP Request ID	M	
		SIR 3.02	PMM-RSP Location	M	
		SIR 3.03	PMM-RSP DSRC Support Indicator	M	
		SIR 5.01	PMM-ARRIVE Request ID	M	
		SIR 5.02	PMM-ARRIVE Location (lat/long/elev)	M	
		SIR 5.03	PMM-ARRIVE ETA	M	
		SIR 5.04	PMM-ARRIVE Visible Vehicle ID	M	
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of the sequence diagrams define to address user need
		PR 5.02	No interference of PMMs with PSMs and BSMs	M	
UN 5.04	Stop sending travel / ride request messages when entering vehicle			M	
		FR 6.01	Detecting when entering DSRC equipped Light Duty vehicle	M	
		FR 7.01	Detecting when entering DSRC equipped transit vehicle	M	
		FR 7.03	Detecting presence of Bluetooth connectivity in transit vehicle	M	Only for demonstrations involving transit vehicles equipped with Bluetooth iBeacons
		SIR 8.30	Coordination End Message ID	M	
		SIR 8.31	Coordination End Travel Group ID	M	
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
				M	
UN 5.05	Stop sending personal safety messages when entering equipped vehicle			M	
		FR 6.02	Detecting when entering non-DSRC equipped Light Duty vehicle	M	
		FR 7.02	Detecting when entering non-DSRC equipped transit vehicle	M	
		FR 7.03	Detecting presence of Bluetooth connectivity in transit vehicle	M	Only for demonstrations involving transit vehicles equipped with Bluetooth iBeacons

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 20.05	Requesting and Entering a Ride with a DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
				M	
				M	
UN 5.06	Leaving ad-hoc travel group			M	
		FR 5.08	Leaving an ad-hoc travel group based on distance	M	
		FR 5.10	Disbanding an ad-hoc travel group when entering a vehicle	M	
		FR 5.11	Normal disbanding an ad-hoc travel group	M	
		PR 1.11	Capture 90% of Coordination Messages sent over Wi-Fi-Direct	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
				M	
UN 6.0	Mobile Device Acting as Vehicle Message Provider Needs			M	
UN 6.01	Sending individual Surrogate BSMs			M	
		FR 3.01	Generating Surrogate BSMs	M	
		FR 3.01.01	Generating Surrogate BSM Content	M	
		FR 3.02	Broadcasting Surrogate BSMs	M	
		FR 3.03	Receiving Surrogate BSMs	M	
		FR 6.02	Detecting when entering non-DSRC equipped Light Duty vehicle	M	
		FR 7.02	Detecting when entering non-DSRC equipped transit vehicle	M	
		SIR 6.01	Surrogate BSM Location (lat/long/elev)	M	
		SIR 6.02	Surrogate BSM Speed	M	
		SIR 6.03	Surrogate BSM Heading	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 6.04	Surrogate BSM Indicator	M	
		SIR 15.07	Surrogate BSM over DSRC	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2736:2016 if MSGs and Des fulfill requirements	M	
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		PR 1.05	Mobile device - Determining Vehicle Size and Length	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
				M	
UN 6.02	Stop sending Surrogate BSMs			M	
		FR 6.04	Detecting when exiting non-DSRC equipped Light Duty vehicle	M	
		FR 7.05	Detecting when exiting non-DSRC equipped transit vehicle	M	
		SIR 20.04	Requesting and Entering a Ride with a non-DSRC-equipped Light Duty vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		SIR 20.06	Requesting and Entering a Ride with a non-DSRC-equipped Transit Vehicle	M	Parts of this sequence are applicable to fulfill this User Need
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
UN 6.03	Receiving Surrogate BSMs			M	
		FR 3.03	Receiving Surrogate BSMs	M	
		FR 4.03	Receiving BSMs	M	
		SIR 7.01	BSM Location (lat/long/elev)	M	
		SIR 7.02	BSM Speed	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		SIR 7.03	BSM Heading	M	
		SIR 7.04	BSM Vehicle Size	M	
		SIR 7.05	BSM Vehicle Travel Lane	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 17.01	Conform to existing, standardized data element definitions	M	
		SIR 17.01.01	Use J2736:2016 if MSGs and DEs fulfill requirements	M	
		PR 5.01	No interference between PSMs and BSMs	M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
UN 7.0	Mobile Device Performance Needs			M	
UN 7.01	Alert/Warning display within 0.5 seconds from message receipt			M	
		PR 1.15	Display Message Content within 0.1 seconds after receipt of message content	M	
				M	
UN 7.02	Location detection accuracy			M	
		PR 1.01	Mobile device lane level positioning accuracy	M	
		PR 1.02	Mobile device unsafe zone detection accuracy	M	
		PR 1.03	Mobile device path history (20 secs)	M	
		PR 1.04	Mobile device path prediction (5 secs)	M	
		PR 2.02	Vehicle lane level positioning accuracy	M	
				M	
UN 7.03	Mobile Device Communications from an ad-hoc travel group not interfering with communications by other travelers or other travel groups			M	
		PR 5.06	No interference of Coordination Messages with Coordination Messages from another ad-hoc travel group	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		PR 5.07	No interference of Coordination Messages with Coordination Messages from several other ad-hoc travel groups	M	
				M	
UN 8.0	System Monitoring Needs			M	
UN 8.01	Logging of all messages sent and received			M	
		FR 10.01	Recording all DSRC communications within RSE	M	
		FR10.02	Recording all cellular communications via cloud infrastructure system	M	
		FR 10.03	Recording all sent and received communications within Mobile Device	M	
		FR 10.05	Recording all sent and received communications within Vehicle	M	
		SIR 16.01	RSE to receive all DSRC communications	M	
		SIR 16.02	Cloud Infrastructure equipment to receive all cellular communications	M	
		DR 1.01	Store all mobile device data transmissions for the duration of test plan execution	M	
		DR 2.01	Store all vehicle data transmissions for the duration of test plan execution	M	
		DR 3.01	Store all roadside equipment DSRC data transmissions	M	
		DR 4.01	Store all roadside equipment cellular data transmissions for the duration of test plan execution	M	
				M	
UN 8.02	Logging of all messages displayed on a device screen			M	
		FR 9.05	Recording all displayed messages within Mobile Device	M	
		FR 9.06	Recording all displayed messages within Vehicle	M	
		DR 1.02	Store all mobile device screen displays for the duration of test plan execution	M	

User Need ID	User Need	Req ID	Requirements Title	Conformance	Additional Specifications
		DR 2.02	Store all vehicle screen displays for the duration of test plan execution	M	
				M	
UN 8.03	Provision of Reliable Equipment (Vehicles, Mobile Devices, Roadside Equipment, Cloud Infrastructure)			M	
		RR 1.01	Mobile Device operates for at least 3 hours	M	
		RR 1.02	MDEA runs without need to restart	M	
		RR 1.03	DSRC infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
		RR 2.01	VEA operates for at least 3 hours	M	
		RR 2.02	VEA runs without need to restart	M	
		RR 2.03	Bluetooth iBeacon operates for at least 3 hours	M	
		RR 3.01	Roadside equipment operates for at least 3 hours	M	
		RR 3.02	Roadside equipment application runs without need to restart	M	
		RR 4.01	Cloud infrastructure operates for entire test plan duration	M	
		RR 4.02	Cloud infrastructure runs without need to restart	M	
		RR 4.03	Cellular infrastructure available for entire test period without interruptions or lack of coverage at test facility	M	
				M	

Source: Battelle

APPENDIX A Acronyms and Abbreviations

Acronym	Description / Explanation
ADA	Americans with Disabilities Act
API	Application Program Interface
AVL	Automatic Vehicle Location
BSM	Basic Safety Message (see also Terms and Definitions)
CAN	Controller-Area Network
ConOps	Concept of Operations
DCM	Data Capture and Management
DMA	Dynamic Mobility Applications Program
DSRC	Dedicated Short Range Communications
ETA	Estimated Time of Arrival
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GTM	Government Task Manager
I2V	Infrastructure-to-Vehicle
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
LTE	Long-Term Evolution
MAP	Geographic information about an intersection (see also Terms and Definitions)
NFC	Near Field Communication
OBE	On-Board Equipment
OEM	Original Equipment Manufacturer
OS	Operating System
OSU	Ohio State University
PMM	Personal Mobility Message (see also Terms and Definitions)
PSM	Personal Safety Message (see also Terms and Definitions)
RFID	Radio Frequency Identification

Acronym	Description / Explanation
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing Message (see also Terms and Definitions)
SysReqs	System Requirements
TCP/IP	Transmission Control Protocol/Internet Protocol
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
WAVE	Wireless Access in Vehicular Environments
Wi-Fi	Wireless Fidelity
XML	Extensible Markup Language

APPENDIX B Terms and Definitions

Term	Definition
Accelerometer	Hardware sensor that measures the acceleration force on the device along three axes.
Ad-hoc Travel Group	Travel group that is formed though mobile device-to-mobile device communications.
Advisory	As used in Advisory Message vs Alert Message vs Warning Message. Advisory Messages are issued when a pedestrian is in the area.
Alert	As used in Advisory Message vs Alert Message vs Warning Message. Alert Messages are issued when a pedestrian is in the travel lane ahead.
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.
GNSS	The term GNSS includes satellite systems deployed by various nations and regions including the U.S.-based GPS, the Russian GLONASS, and European Union's Galileo.
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.
Linear Acceleration	Software sensor that estimates the acceleration force of the device along three axes, excluding gravity.
Magnetometer	Hardware sensor that measures the geomagnetic field surrounding the device along 3 axes.
MAP Message	J2735-defined message called MAP, a reference to the function of this message to define the geographic layout of an intersection.
Message Type	Type of personal safety or personal mobility message that is transmitted based on the technology used and level of coordination available.

Term	Definition
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.
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.
SPaT Message	J2735-defined message called SPaT, which stands for 'signal phase and timing', which contains the current traffic light indications for an intersection as reported by the local traffic signal controller.
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.
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.
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.
Warning	As used in Advisory Message vs Alert Message vs Warning Message.

Term	Definition
	Warning Messages are issued when a pedestrian is in the travel lane ahead.
Wi-Fi	Local area wireless technology that allows enabled devices to connect to the Internet

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:

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

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)[1]
- 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.

[1] 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.[2] 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[3] 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)

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

[3] 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:

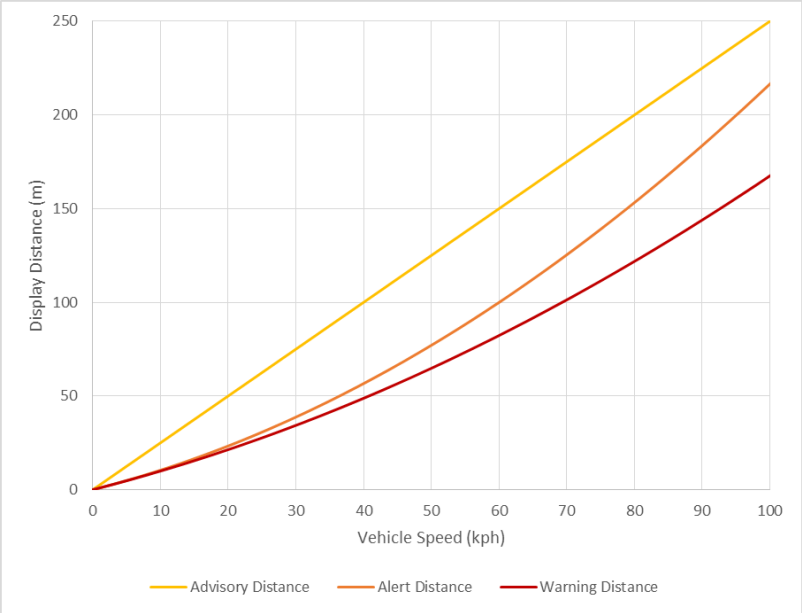
$$d_{alert} = 1.1 * \left\{ [(0.5 + 2.5) * v] + \frac{v^2}{2(3.4)} \right\}$$

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

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 9 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 9. Message Display Distances

U.S.Department of Transportation
Federal Highway Administration

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

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

FHWA-JPO-16-423
July 2016