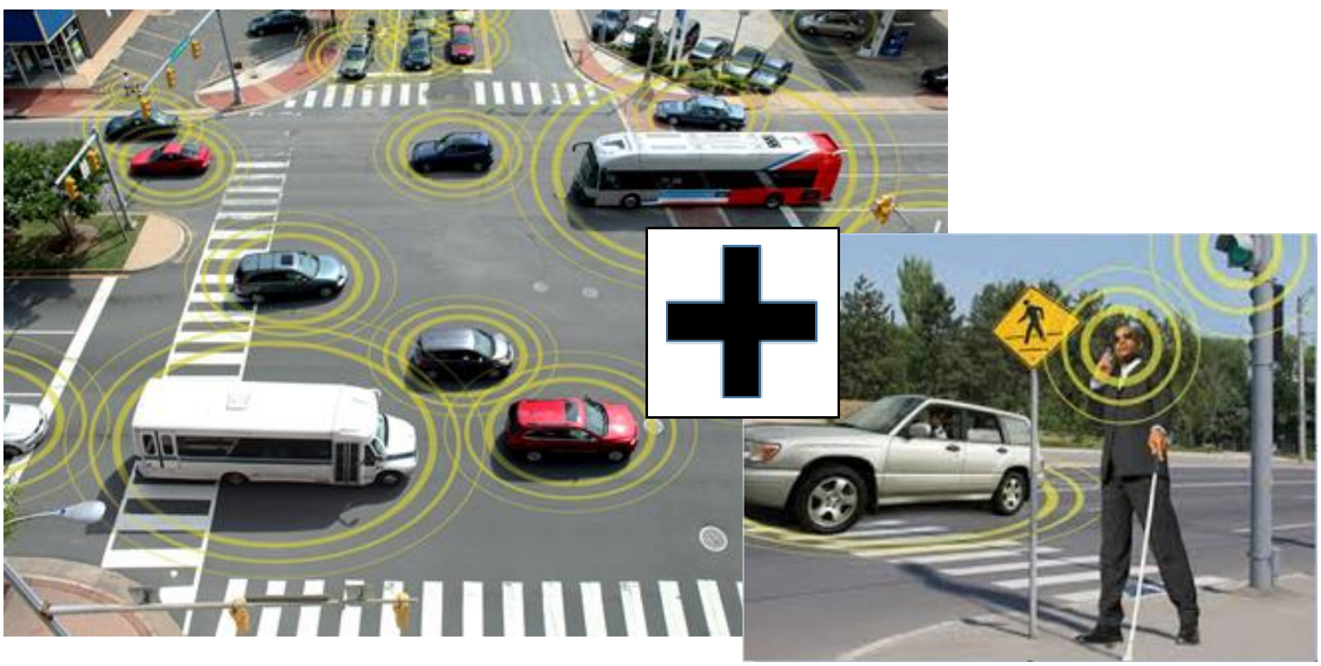
Sharing Data Between Mobile Devices, Connected Vehicles and Infrastructure

Task 3: Concept of Operations

Technical Memorandum – Final

www.its.dot.gov/index.htm
Revised Report — July 13, 2016
FHWA-JPO-16-422



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

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-16-422		

4. Title and Subtitle	5. Report Date
Sharing Data Between Mobile Devices, Connected Vehicles and Infrastructure - Task 3: Concept of Operations Technical Memorandum –Final	July13, 2016
	6. Performing Organization Code
7. Author(s) Original: Bennett Pierce, Richard Brooks, Thomas Timcho, Robert Zimmer. 2nd Revision: Dr. Chris Toth, Tom Timcho, Sudhakar Nallamothu, Joerg 'Nu' Rosenbohm	8. Performing Organization Report No.
9. Performing Organization Name And Address Battelle 505 King Avenue Columbus, OH 43201	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. DTFH61-12-D-00046
12. Sponsoring Agency Name and Address U.S. Department of Transportation FHWA Office of Operations Research and Development Turner-Fairbank Highway Research Center 6300 Georgetown Pike McLean, VA 22101	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report describes the concept of operation for the use of mobile devices in a connected vehicle environment. Specifically, it identifies the needs, conceptual system, and potential scenarios that serve as the basis for demonstrating both safety and mobility benefits of using these devices, and how the interactions and messaging of these devices may be coordinated in order to provide more efficient, and less congested exchange of information, as well as how these devices might behave left uncoordinated.
Within this 2nd revision, a User Needs section, additional features focusing on adding connectivity to back-office functions in form of additional steps within the scenarios to include roadside equipment units were added.

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	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
None	None	86	

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

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Chapter 1 Scope

The United States Department of Transportation (U.S. DOT) has conducted significant research on the use, benefits, and operational issues associated with using dedicated short-range communications (DSRC) and cellular devices in both vehicular and infrastructure-based communications. Specifically, the benefits are intended to improve the safety, mobility and environmental impact on our surface transportation system. 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 it 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 WiFi 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 device, vehicles, and infrastructure. This is intended as a research project and therefore does not seek to identify, define, summarize, or propose a system suitable for immediate wide-scale deployment.

1.1 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.

1.2 Document Overview

The purpose of this document is to provide a summary, at a conceptual level, of the system and scenarios that will be created, tested, and demonstrated during this project. This document will serve as a platform for U.S. DOT and other stakeholders to confirm the concept is aligned to the objectives of this project. Ultimately, the concept and scenarios will serve as a basis for determining system requirements and demonstration test plans. This document is the third version of the Concept of Operations (2nd revision) in which the user needs section and additional features pertaining to back-office functionalities for transit and transportation management within the scenarios were added based on request by the U.S. DOT. Very few other, mostly editorial changes were made between the 'Revised Concept of Operations' Draft from July 16, 2015 and this version.

The primary audience for this document is U.S. DOT staff and other identified stakeholders who are leading and interested in understanding the impact of safety and mobility messages from mobile devices within the envisioned connected vehicle environment where DSRC, Cellular, WiFi, 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 system requirements.

Chapter 2 Referenced Documents

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

2.1 Works Cited

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

2.2 Works Consulted

- "Connected Vehicle Certification Program," available at http://www.its.dot.gov/factsheets/certification_factsheet.htm
- "Conduct Scan of Technology, Application Standards, and Stakeholder Engagement," Draft Final Report, Battelle, 2015, Contract Number: DTFH61-12-D-00046
- Candidate Improvements to Dedicated Short Range Communications (DSRC) Message Set Dictionary [SAE J2735] Using Systems Engineering Methods, SAE J3067, 2014-08-26
- Dedicated Short Range Communications (DSRC) Message Set Dictionary™, SAE J2735, 2009-11-19
- Dedicated Short Range Communications (DSRC) Message Set Dictionary™, SAE J2735-2016, published version.
- Performance Requirements for Safety Communications to Vulnerable Road Users, SAE J2945/9, draft version obtained in November 2015.
- IEEE 802.11™: Wireless LANs Standards
- U.S. DOT, About ITS Standards. http://www.standards.its.dot.gov/LearnAboutStandards/NationalITSArchitecture)
- Message Sets for Advanced Traveler Information System (ATIS), SAE 2354, 1999-11-27
- Technical Memorandum: Analysis of Deployment Readiness for Early Adoption and Testing of V2I Applications and Systems by State and Local Agencies, prepared by Booz Allen Hamilton for US DOT, April 13, 2015
- Final Report: SmarTrAC: A Smartphone Solution for Context-Aware Travel and Activity Capturing, Fan, Yingling, et al., http://www.its.umn.edu/Publications/ResearchReports/pdfdownload.pl?id=2588
- US DOT Vehicle to Pedestrian (V2P) Technologies Database http://www.its.dot.gov/press/2015/V2P_TechScanDatabase.xlsx
- Proposed extended BSM Messages to be Used in the Analysis, Preliminary Draft, January 3, 2015, as prepared by ARINC Incorporated for US DOT under Contract DTFH61-10-D-00015, Task Order 1403.
- Technical Report 1: Data Capture and Management Program Standards-related Requirements Collected, as prepared by ConSysTec, et. al, under contract to Cambridge Systematics for US DOT, March 30, 2015
- DCM Database, as prepared by ConSysTech in support of US DOT Data Capture and Management Program, March 30, 2015
- Development of the Long-Term Connected Vehicle Standards Framework, Final Draft, Version 2.1, November 13, 2014, as prepared by SAE International, et. al, for US DOT.

Chapter 3 Current System or Situation with Mobile Devices in the Connected Vehicle Environment

The U.S. DOT has established a strategic plan and vision under which, "future cars, trucks, buses, the roadside, and our smartphones will talk to each other. They will share valuable safety, mobility, and environmental information over a wireless communications network that is already connecting and transforming our transportation system as we know it. Such a system of 'connected vehicles', mobile devices, and roads will provide a wealth of transportation data, from which innovative and transformative applications will be built.[1]" As part of implementing this vision, U.S. DOT has launched, and is continuing to launch, research programs and activities related to connected vehicles. These include sponsoring connected vehicle research in mobility, safety, environment, road weather, policy, and in the fundamental technologies envisioned as providing the "connectivity" to these vehicles, infrastructure components, and mobile devices.[2] Additional research and activities continue to be conducted regarding the underlying standards, protocols, message sets, and operational and situational conditions that could/will be used to exchange information with this connectivity.

The role of mobile devices within the connected vehicle environment is one such research activity that has previously been explored through projects such as the Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning[3] where mobile devices were used as "nomadic" connected vehicle equipment. On-going and future research projects, including this project, are also being implemented to explore and understand the impact that DSRC equipped mobile devices might have on the overall connected vehicle environment.

3.1 Background

The U.S. DOT has identified multiple roadmaps of research, development and deployment that have focused on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) initiatives, including prototype activities for several safety, mobility and environmental-friendly applications. The majority of these have built on the 5.9GHz DSRC frequency band that is an experimental license from the National Telecommunications and Information Administration to U.S. DOT for development and exploration. Operational licenses can only be held by non-Federal applicants, and these operational licenses are administered by the Federal Communications Commission. Coinciding with the adopting and refining of this 5.9 GHZ DSRC wireless technology, several data exchange standards were developed that support both the V2V and V2I initiatives, often leveraging legacy Intelligent Transportation Systems (ITS) standards, resulting in newer vehicle-centric standards such as SAE J2735:2016. Small and Large-scale demonstrations, including those conducted by the Crash Avoidance Metrics Partnership

[1] "2015-2019 ITS Strategic Research Plan" available at http://www.its.dot.gov/strategicplan/

[2] http://www.its.dot.gov/research.htm

[3] http://www.its.dot.gov/dma/bundle/inflo_plan.htm

(CAMP), those conducted at Turner-Fairbank Highway Research Center (TFHRC), and the Safety Pilot Model Deployment in Ann Arbor, MI have demonstrated the success of this wireless technology and are an indicator of the associated future potentials.

Coinciding with these activities in the U.S., both Japan and the European Union (EU) have begun research and deployment of similar wireless technologies. To maximize research opportunities and leverage lessons learned, as well as to move towards a common technology and architecture, each of these entities is supporting harmonization efforts between the countries. For instance, the working group responsible for the IEEE 1609.x family of standards is proposing revisions to the current standards that aim towards harmonizing the use of these core standards with the International Organization for Standardization (ISO). Similarly, the Society of Automotive Engineers (SAE) is advocating changes that allow for similar standardization globally.

Table 3.1 identifies the predominant domestic standards that guide implementation of messages and data elements that may be relevant to this project. SAE J2735 and the related SAE J2945/9 are of particular interest as they relate directly to the DSRC environment that current V2V and V2I deployments utilize, and are potentially standards that could house future mobile device messages. In particular, J2945/9 is looking at a message for vulnerable road users (VRU). Additionally, J2354, while not originally designed for DSRC communications, offers several message dialogs associated with mobile devices and information sharing.

Table 3.1. Domestic Standards Overview

Identifier	Title	Description
SAE J2735	Dedicated Short Range Communications (DSRC) Message Set Dictionary	Provides the definition and structure of the current suite of DSRC-based messages, which include the Basic Safety Message, emergency vehicle alert, roadside alert, traveler information, signal phase and timing and others. The new version to be published in 2016 will define a Personal Safety Message (PSM). Mobility messages such as a Personal Mobility Message (PMM) are not defined in SAE 2735.
SAE J2945.x	Dedicated Short Range Communications (DSRC) Minimum Performance Requirements	Originally intended to define the minimum performance requirements for SAE J2735 messages. These standards has been expanded to include a handful of message types, including the performance measures for safety communications to Vulnerable Road User (VRU) as described in J9245/9, which is referencing the PSM message type defined in SAE 2735-2016.
SAE J2354	Message Sets for Advanced Traveler Information System (ATIS)	Messages and data elements to convey traveler information via multiple means, including infrastructure, vehicles and mobile devices. Additional discussion of messages from this standard is included below.
SAE J2540	International Traveler Information Systems (ITIS) Phrase Lists	Code lists that allows the construction of multi-lingual traveler information messages. Used by several other standards, including J2735 and J2354.
APTA TCIP	Transit Communication Interface Profiles (mainly Common Public Transport and Passenger Information portions)	Transit-related message standards designed specifically for exchange of information related to transit operations. Additional discussion of messages from these standards is included below.

Identifier	Title	Description
NTCIP 1202	Object Definitions for Actuated Traffic Signal Controller (ASC) Units	Message set standard for configuration, control and status of traffic signal controller, including pedestrian call and walk status indicators. This standard is currently being updated to include CV data elements that are compatible with the several messages defined in J2735:2016 draft, and as such, does not warrant further discussion in this report.
NTCIP 1204	Environmental Sensor Station	Message set standard for the configuration, control and status of environmental sensors that measure conditions of potential impact to traffic operations. Various weather and air quality parameters may be of interest. The standard shares common data elements with J2735, and as such, is accessible via J2735.
NTCIP 1211	Transit Signal Prioritization	Message set standard designed to enable interaction between a priority request generator (e.g. bus or TMC), and the priority request server, generally the traffic controller. Initiation of the functions provided by this standard are expected to be originated by the SRM defined in the SAE J2735 standard.

Source: Battelle / Trevilon

The published SAE J2735:2016 defines the Message Set Dictionary that is expected to be used domestically to meet the majority of the requirements for applications that transfer information amongst vehicles and infrastructure. To date, the Basic Safety Message (BSM) has been the primary message implemented for connected vehicle deployments. Recent research has continued to affirm the use of DSRC for time-sensitive safety messages[4]; however; non-time critical mobility applications can potentially use both DSRC as well as other means of wireless communications.

The BSM is intended for the low latency, localized broadcast required by V2V safety applications. The BSM is specific to vehicle usage as it contains mandatory parameters that can only be provided by or make-sense for a motorized vehicle. These include parameters such as Wiper Status, Lights, Brake Status, Steering Angle, and Road Friction. Similarly, the Probe Vehicle Data (PVD) Message as well as other message types specified in J2735, have these same features/constraints. Additionally, the new version of J2735 includes the definition of the Personal Safety Message (PSM), which defined data elements for x/y location, speed, heading, path history, path prediction, and other data elements addressing pedestrian safety needs.

The SAE J2354 Message Sets for Advanced Traveler Information System (ATIS), describes standardized messages used by information service providers to convey what is known as Advanced Traveler Information Systems (ATIS) data between systems. The messages contained within this standard address all stages of travel (informational, pre-trip and en-route), all types of travelers (drivers, passengers, personal devices, computers, other servers), all categories of information, and all platforms for delivery of information (in-vehicle, portable devices, kiosks, etc.). As it is presently implemented, however, this standard is primarily focused on delivering information to the traveler, and not in the other direction.

One of the newest standards to have emerged, SAE J2945/9, does however define a message identified as the Vulnerable Road User (VRU), references the PSM message defined in J2735. A full

[4] http://www.its.dot.gov/safety_pilot/safety_pilot_progress.htm; http://www.its.dot.gov/dma/index.htm

evaluation of the performance measures for the referenced, J2735-defined PSM cannot be made until both the J2945/9 has been approved (it is presently in working draft form), and the detailed requirements have emerged from this project, but the project team will continue to coordinate with the SDO to help understand and guide the development of the VRU to satisfy the needs established for the PSM. J2945/9, or any other SAE standards do not provide any representative message that would fulfill the needs associated with a Personal Mobility Message (PMM) or other enabling message exchanges discussed in this Concept of Operations.

Connected vehicle technology and the data-rich environment it enables has also resulted in the need for a consistent, national approach to implementation of these systems, and the enormous data capture and management opportunities that accompany these technologies. Efforts related to both of these initiatives are currently underway within the U.S. DOT.

The National Intelligent Transportation Systems (ITS) Architecture[5] provides a common framework for the planning, development and integration of ITS deployments. The program was initiated in 1993 by the U.S. DOT to develop a single framework that could guide the development and implementation of ITS user services over a 20-year timeframe. The National ITS Architecture defines the system, the role of each component within the system, and how information is shared and exchanged among components. It contains over 30 user services, which were developed through stakeholder input from public, academic and private sector ITS stakeholders throughout the U.S. Recent systems engineering and prototyping efforts associated with U.S. DOT's Dynamic Mobility Applications program, and other similar connected vehicle research projects, have contributed a whole new class of application bundles, which serve as guides to deployments within the connected vehicle environment, and are also now available as open-source projects to the deploying public as part of the Open Source Application Development Portal.[6] Table 3.2 illustrates the range of the National ITS Architecture components.

Table 3.2. National ITS Architecture – ITS User Services

Travel and Transportation Management	**Commercial Vehicle Operations**
• En-Route Driver Information • Route Guidance* • Traveler Services Information* • Traffic Control* • Incident Management • Emissions Testing and Mitigation	• Commercial Vehicle Electronic Clearance • Automated Roadside Safety Inspection • On-Board Safety Monitoring • Commercial Vehicle Administrative Processes • Hazardous Materials Incident Response • Commercial Fleet Management
Traveler Demand Management	**Emergency Management**
• Pre-Trip Travel Information* • Ride Matching and Reservation* • Demand Management and Operations	• Emergency Notification and Personal Security • Emergency Vehicle Management
Public Transportation Operations	**Advanced Vehicle Control and Safety Systems**

[5] Source: http://www.iteris.com/itsarch/html/user/userserv.htm

[6] http://www.itsforge.net/

• Public Transportation Management*	• Longitudinal Collision Avoidance
• En-Route Transit Information*	• Lateral Collision Avoidance
• Personalized Public Transit*	• Intersection Collision Avoidance*
• Public Travel Security	• Vision Enhancement for Crash Avoidance
Electronic Payment	• Safety Readiness
	• Pre-Crash Restraint Deployment
• Electronic Payment Services*	• Automated Highway Systems

* User Services with potential connected vehicle / mobile device touch points

Source: Battelle as adapted from the National ITS Architecture

In 2014, the U.S. DOT initiated a new effort, the Connected Vehicle Reference Implementation Architecture (CVRIA). It is an expansion component of the National ITS Architecture and defines standards and processes associated with connected vehicles and its interfaces.[7]

3.2 Objectives, and Scope

The *Coordination of Mobile Devices for Connected Vehicle Applications* project aims to enhance the connected vehicle environment by incorporating the *mobile device* in order to facilitate the transmission of personal safety messages (PSM) and personal mobility messages (PMM) that interact with these other systems (i.e.: P2V and P2I exchange of messages). This project seeks to utilize the mobile device as a medium for messages that complement those transmitted by vehicles by adding the connected “person” fleet dimension to the existing connected vehicle environment. One of the critical aspects to this project is the concept of “coordination” between devices in a connected vehicle world. In the context of this project, “coordination” refers to the ability of the various devices, both mobile and “carry-in” to interact and exchange information so that a consistent and consolidated message is presented externally. As an example, consider the scenario whereby three persons all with mobile devices are car-sharing a vehicle and further, all three mobile devices are broadcasting “personal probe” messages. Without coordination, this would result in essentially identical messages being broadcast creating a potential for confusion as other systems interact with this vehicle, and potential creating over-saturation conditions on the communications channels. . Alternatively, from a coordinated perspective, the three mobile devices and the vehicle could coordinate the information from these different sources into a representative message broadcasted from a single source. As the characteristics change over time for each traveler, the opportunities for coordination will also change. This could result in several different types of messages or message content to facilitate this coordination, including:

- Basic Position Message – this type of message would provide a location of each mobile device that could be used to determine that they are “eligible” for coordination.
- Communication Protocols Available – this type of message would provide a summary of the communication protocols, operating system, etc. available to the mobile device and indicate which protocol is to be used for coordinating with other mobile devices, vehicles, and nodes.

[7] (U.S Department of Transportation, Joint Program Office, ITS Standards Program. Retrieved from: http://www.its.dot.gov/press/2013/connected_vehicle_Architectureworkshop.htm)

- Mobile Device State – this type of message would provide information on the state of the mobile device as it relates to mobility and safety (i.e., in a coordinated state, in uncoordinated state, not available for coordination, etc.).
- Coordination Request/Response – this type of message would be used by the mobile devices to initiate and implement coordination with each other or with a vehicle and/or node.
- De-Coordination Request/Response – this type of message would be used by the mobile devices to cease coordination.

At the same time, we would expect there to be different messages that would convey information specific to mobile devices such as:

- Personal Safety Message – this type of message would provide information that would relate to safety and would include elements such as state of the traveler (i.e., stationary, moving), number of travelers (if this message is being coordinated among several mobile devices), and even additional information such as projected path, etc.
- Personal Mobility Message – this type of message would provide information on the traveler such as mobility needs, schedule constraints, etc.

All of these various message types need to be examined against existing standards, message sets, communication protocols and overall operational conditions related to connected vehicles. This type of experimentation, testing, and examination is the goal of this project, with three primary objectives being to:

1. Evaluate the potential benefit and potential issues associated with the transmission of mobility and safety messages from hand-held mobile devices via alternative communications media.
2. Develop and test modifications to mobility and safety messages for mobile devices that complement existing and emerging standardized messages from vehicles, and coordinate those proposed modifications with mobility application developers and standards development organizations.
3. Create and demonstrate potential methods for coordinating safety and mobility messaging linking mobile devices carried by pedestrians into light and transit vehicles that may or may not themselves be capable of generating one or more related safety and mobility messages.

To achieve the project goals and objectives, a series of experiments, tests, and scenarios that involve connected vehicles as well as mobile devices with DSRC capabilities will be conducted. These experiments will capture data and expect to identify operational constraints, issues, and other considerations for integrating mobile devices into the connected vehicle environment. These experiments will consist of both controlled field tests that will examine specific aspects of the communications (i.e., small scale scenarios) and a larger naturalistic study (i.e., large scale scenarios). The types of research questions and data that will be examined through these scenarios include:

- Gathering evidence and data to determine the utility and performance of different communication methods such as Bluetooth, WiFi, WiFi-Direct, DSRC, Cellular, near-field communications (NFC), etc. for the exchange of information between mobile devices and connected vehicle components including potential rapid, low latency data exchanges.

- Exploring the ability of mobile devices to switch between communication protocols such as DSRC, Cellular, and WiFi without interruption of message communication.
- Quantifying the latency between communication transfers.
- Determining whether there is any potential impact on the anticipated safety or mobility benefits when there are a large number of uncoordinated mobile devices simultaneously interacting with connected vehicle components; and whether this can be mitigated through coordination activities between mobile devices and/or connected vehicles.
- Alternatively, determine the implications of a broadly unconstrained and uncoordinated deployment of mobile devices and connected vehicles operating in close proximity for connected vehicle applications.
- Assessing the potential policy and technical issues that can be anticipated for dense connected vehicle/connected mobile device deployments.

The remainder of this document describes the system concepts, the rationale for key concept decisions, detailed system needs (data, interface, interoperability, communications, output needs etc.), and operational scenarios for this experimentation, testing, and examination. Following this ConOps, will be a detailed System Requirements, System Architecture, and Design document as well as an Experimental Test and a Field Test Site Plan which will provide, at a detailed level, the specific experiments, scenarios, software, testing, and data collection activities.

3.3 Operational Policies and Constraints

Mobile devices are virtually ubiquitous in the U.S. population and are widely utilized by most segments of the population.[8] However, within the connected vehicle environment, emphasis to date has been focused upon vehicle-to-vehicle, and vehicle-to-infrastructure applications and communications. This environment is architected largely upon the use of a low-latency, wireless broadcast technology, to communicate messages between entities. This role has been proven to be fulfilled using DSRC technology, and some form of technology that encompasses DSRC has been developed and tested in a number of different research projects, pilot deployments, and demonstrations. However, a connected vehicle system, with large numbers of both vehicles and infrastructure equipment capable of communicating using DSRC, has not yet been deployed widely across the U.S. The system described in this document, therefore, represents largely experimental systems based upon these previous pilot and demonstration deployments.

The development and deployment of the system described herein is envisioned as a limited demonstration designed to specifically investigate communication messages and protocols associated with integrating mobile devices into this envisioned connected vehicle environment. It is not intended for a geographically large or universal deployment.

[8] "Smartphone OS Market Share, Q4 2014." IDC. http://www.idc.com/prodserv/smartphone-os-market-share.jsp

3.4 Description of the Current System or Situation

Currently, mobile devices in the U.S. generally include a number of different communication technologies as illustrated in Table 3.3; however, what is not generally available is embedded DSRC capabilities within mobile devices. As a result, mobile devices are currently included within the connected vehicle environment as devices that can send and receive information, but not as DSRC-enabled devices that are actively integrated with vehicles, infrastructure components, or each other.

Table 3.3. Communication Technologies Commonly Found in Mobile Devices Available in the U.S.

Type	Description
Bluetooth 'Classic' 4.0	• Supports data transmission of up to 100 meters at a maximum rate of 1 Mbps. • Unique device identifiers (MAC address) may be obtained during pairing process, without having to complete the pairing. • Supports TCIP/IP and UDP formats, however, Serial Port Profile (SPP), is the most common method used for data interchange.
Bluetooth LE	• Similar range but has reduced transmission rates as compared with 'classic' Bluetooth, the emphasis being on decreased power consumption • Designed for applications that do not need to exchange a lot of information • Supports IPv6/6LoWPAN as the primary mechanism for data interchange
WiFi	• Supports Infrastructure and Ad-Hoc Modes • Unique device identifiers may be obtained without a WiFi connection (SSID). • Supports data transmissions of up to 1500 ft. at a maximum rate of 54 Mbps • Available with encryption/security or open
NFC	• Short-range communication (typically 1-2 inches). • Facilitates contactless mobile payments. • Not available on all iOS mobile devices.
Mobile Network	• Providers have network API features that may be used to obtain location information; terminal status; and service provider.

Source: Battelle

As an illustration of the current role and vision of mobile devices within the connected vehicle environment, it is useful to examine the architecture and architectural elements for a connected vehicle/Dynamic Mobility Application that includes mobile devices. The architecture for many of these applications can be viewed via the Connected Vehicle Reference Implementation Architecture (CVRIA)[9] and using the CVRIA-associated SET-IT tool[10] developed by Federal Highway

[9] See http://www.iteris.com/cvria/

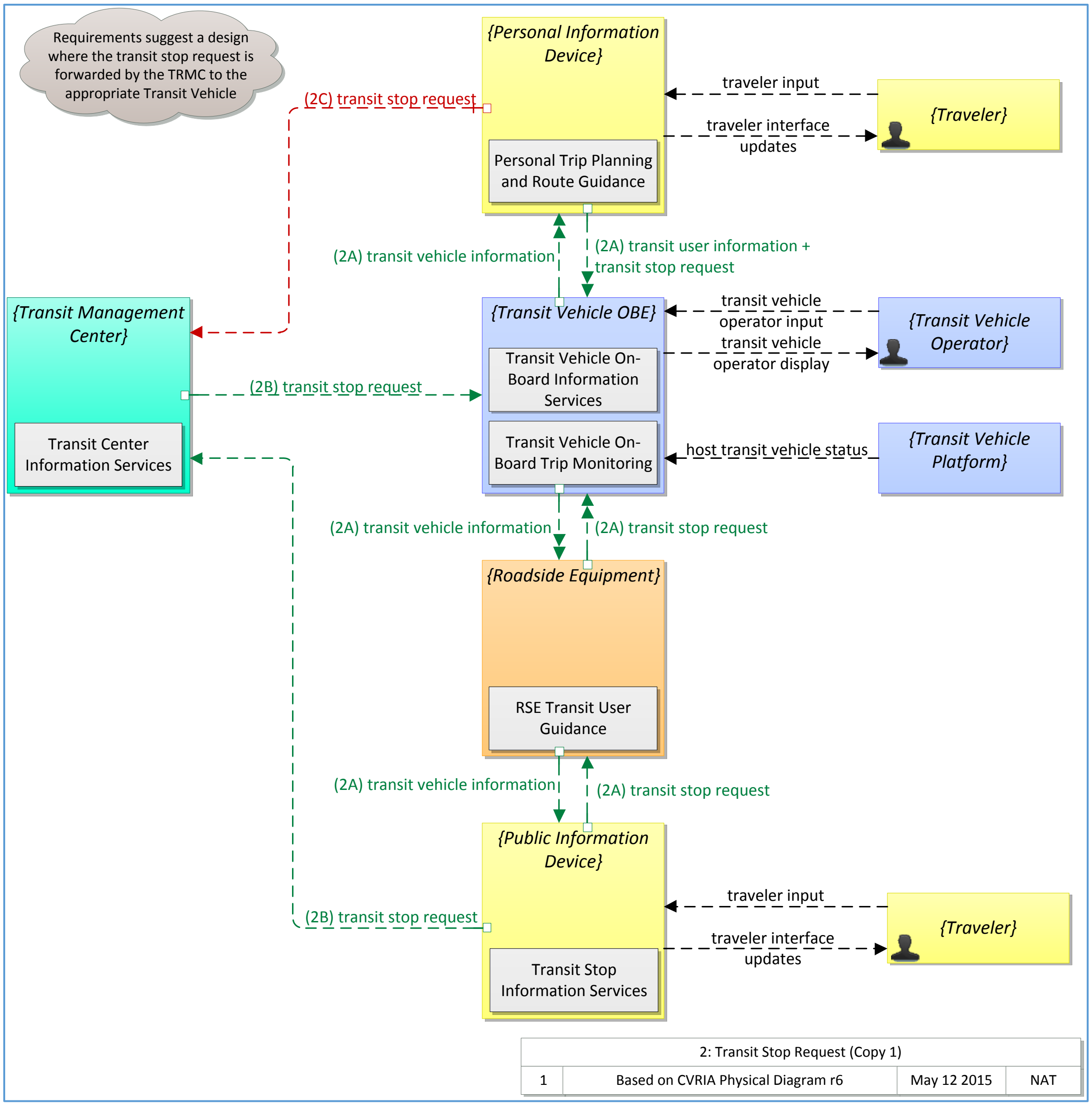
[10] SET-IT is a software tool that integrates drawing and database tools with the Connected Vehicle Reference Implementation Architecture (CVRIA). SET-IT allows users to develop project architectures for connected vehicle pilots, test beds and early deployments. Included in this toolset are a number of different defined "Applications" that are envisioned within the connected vehicle environment.

Administration as an overall framework for these applications within the connected vehicle environment.

One of several applications included in the CVRIA and the SET-IT tool that includes connected vehicles, infrastructure components, and mobile devices is the “Transit Stop Request” application. Figure 3-1 shows a view of this architecture as produced, un-modified, from SET-IT. This architecture includes communication to and from individual travelers, drivers, and pedestrians to vehicles, infrastructure components, and even other travelers, drivers, and pedestrians, and is a good construct to build upon to address the fundamental research objectives of this project. It should be noted that this application was selected only for convenience to illustrate the overall current vision of the connected vehicle environment.

The “Transit Stop Request” application, like all of the other applications included in the SET-IT tool, clearly identifies interactions between a traveler/passenger’s mobile device and the transit vehicle and/or other infrastructure components. Within the SET-IT tool, the architectural element “Personal Information Device” represents mobile devices such as smartphones, tablets, or other such equipment, and is depicted within a yellow box. The conceptual diagrams available within the SET-IT tool all depict a concept where only one traveler is communicating to an infrastructure component at any one time. The diagrams do not currently address the “coordination” among multiple mobile devices. Additionally, the existing architectural flows assume that when a traveler enters a vehicle, only the vehicle operates and communicates within the connected vehicle environment (i.e., the traveler’s mobile device is assumed to automatically “coordinate” with the vehicle).

It is important to note that while useful as a construct to illustrate the current vision of mobile devices within connected vehicle applications, the intent of this ConOps and in fact the entire project is not to develop a new connected vehicle application, but rather to explore and test the potential for benefits and potential issues with the introduction of coordinated mobile devices within existing connected vehicle applications through a series of experiments and tests.



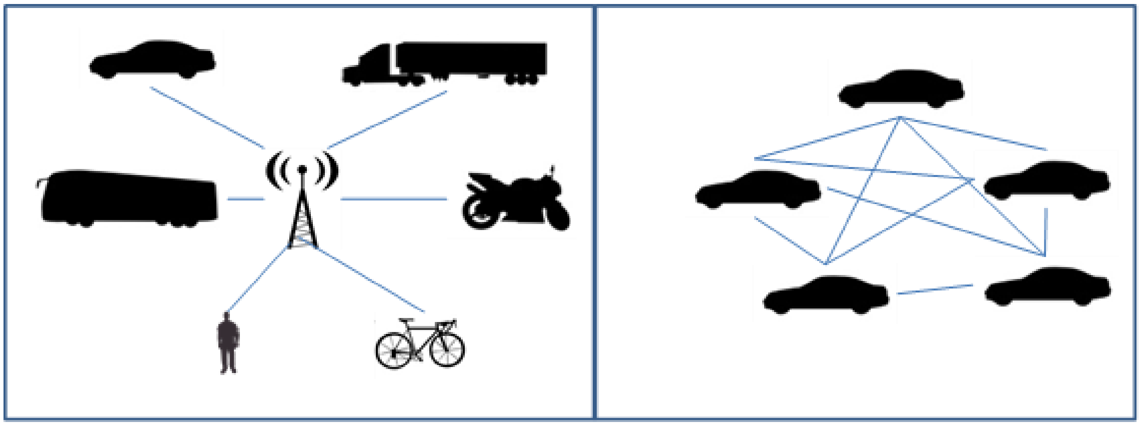
Source: SET-IT Tool

Figure 3-1. System Diagram of the "Transit Stop Request" Application as defined in the CVRIA

3.5 Modes of Operation for the Current System or Situation

As illustrated in both the ITS Architecture and the CVRIA, the current connected vehicle system has a wide variety of different functional and operational modes whereby messages and communications are exchanged between vehicles, infrastructure, and travelers. Generally, the overarching structure widely employed across connected vehicle applications and deployments focuses heavily upon an "infrastructure-based" communications design for V2I communication and V2P (Vehicle-to-Mobile Passenger/Pedestrian), and P2I (Pedestrian Mobile-to-Infrastructure) (see left side of Figure 3-2).

V2V communication is generally conceptualized as an "ad-hoc" network between vehicles (see right side of Figure 3-2).



V2I, V2P, and P2I Uses Infrastructure-Based   V2V Uses "Ad-Hoc" Network

Source: Battelle

Figure 3-2. Generalized System Designs for V2I, P2I, P2V, and V2V Under the Connected Vehicle Architecture

Certainly, there are specific applications within the connected vehicle environment that may "mix-and-match" these two contrasting types of systems depending upon the messages being sent and or distributed. For example, within the Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Application Bundle[11], first responder vehicles communicate with infrastructure components using a client-server design and with oncoming vehicles under a peer-to-peer design while approaching the incident. Once they reach the incident, these first responder vehicles continue to communicate between themselves using a peer-to-peer design, but coordinate their messages related to the incident so that only one first responder vehicle is communicating incident information to oncoming vehicles.

Presently, individual communication devices (e.g., mobile devices) have been included in existing connected vehicle research and demonstrations such as those associated with the R.E.S.C.U.M.E. and Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning.[12] In cases where such devices were included, such as in the INFLO application, these mobile devices, referred to in that study as "nomadic devices," were operated under the constraint that they were the only connected device in the vehicle (i.e., the vehicle was not also a connected vehicle). In other words, "coordination" was not a requirement.

Current connected vehicle deployments employ a variety of different methods to communicate safety, mobility, and other information. These communication protocols and methods include Bluetooth, radio-frequency identification (RFID), and near-field communications (NFC), but largely rely upon cellular, WiFi, and DSRC communications pathways. Cellular and WiFi are typically used for those messages and applications where latency is not a significant issue (e.g., Queue Warning). DSRC is typically used for those situations where low-latency is a critical requirement for the application (e.g.,

[11] "Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Concept of Operations," Battelle under Contract to FHWA: DTFH61-06-D-0007, 2012.

[12] http://www.its.dot.gov/dma/bundle/inflo_plan.htm

Emergency Electronic Brake Lights). Because these low-latency applications typically require knowledge of a vehicle's or traveler's position, heading, and projected path, BSM, Probe Vehicle Messages, and the new PSM are generally transmitted through the DSRC protocols.

3.6 User Classes and Other Involved Personnel

The current connected vehicle systems support and are used by several user classes. The primary user classes are vehicle operators and infrastructure providers. Additionally, user classes with secondary interactions with the various systems include non-motorized users and political, commercial, industrial, and social interest groups. To a lesser extent, other user classes include vehicle passengers and pedestrians. That is, within the current connected vehicle environment, mobile devices, which are typically used by vehicle passengers and pedestrians, are generally secondary user classes as the focus has been primarily on those user classes that operate equipment with DSRC technology. In contrast, when considering mobile devices, the user classes described below all remain as important user classes, but the emphasis shifts (as can be noted in the scenarios described in Chapter 7) to individuals who operate a mobile device.

3.6.1 Vehicle Operators (Drivers)

Vehicle Operators include operators of all vehicle types and classes, including passenger, transit, commercial, fleet, public safety and public service. These vehicle types and classes also include vehicles that are called and respond to ride-sharing, car pool matching, and e-hailing service requests as well as transit and para-transit vehicles. These users are beneficiaries of the proposed safety applications.

3.6.2 Riders and Passengers

Persons seeking to ride a transit vehicle and those that are passengers in a vehicle such as those called via ride-sharing, car pool matching, and e-hailing service requests are a user class that benefits from connected vehicle applications. In the "Transit Stop Request Application" described above, it is this user class that would be the primary beneficiary of such an application.

3.6.3 Infrastructure Provider

Other than in certain locales where private industry owns and/or operates toll facilities or screening applications, the majority of ITS infrastructure present today has been deployed and is maintained by various local and State public transportation departments and transit properties. Traffic engineers, transit engineers, and maintenance crews/technicians are the primary operators of these infrastructure systems. Traffic engineers design, develop, and implement the traffic and transportation systems at intersections, curves, bridges, and other roadway locations as well as the transportation management and/or operations centers (TMCs/TOCs). Transit engineers design, develop, and implement the transit systems within transit stops, and transit vehicles, as well as the transit management centers (TrMCs).

In many cases, communication network engineers are also necessary to maintain communication from the cabinet to a back office for monitoring and management purposes, or the implementation and maintenance is subcontracted. Traffic-specific maintenance crews and technicians are responsible for configuring signal timing plans within the controller; troubleshooting problems with cabinets, controllers, and sensors; and making minor adjustments to the signal timing plans. Transit-specific maintenance crews and technicians are responsible for maintaining equipment at transit stops and within transit vehicles.

3.6.4 Non-Motorized Users

Non-motorized users, which include pedestrians, people with disabilities including wheelchair-bound people, and bicyclists, are a safety consideration at intersections, both signalized and non-signalized, and at other locations within the overall transportation system. As users of the transportation system, they have mobility needs and have different operating characteristics and requirements than motorized vehicles. Current connected vehicle systems tend to group "non-motorized" users as a single entity, when in fact they are more accurately represented as individuals, each with separate safety and mobility needs.

Non-motorized users, also referred to as vulnerable road users, are considered non-motorized users as long as they are outside of a vehicle (transit and/or light-duty vehicles).

For the purpose of this project, non-motorized users include pedestrians and persons with disabilities (but not bicycles) and all are carrying DSRC-enabled mobile devices in order to interact with the other user classes within the Connected Vehicle environment.

3.6.5 Political, Commercial, Industrial, and Social Interest Groups

In any particular region, a number of political, commercial, industrial and/or social interest groups exist that may influence (or desire to influence) how traffic and transit components, including traditional traffic, ITS, and CV components in a region operate. These might include, but are not limited to, political interest groups, businesses and commercial interest groups, special need interest groups, school groups and associations, neighborhood associations and civic organizations, the insurance industry, the research community, legal entities, and private land developers. While not a direct user of the ITS information, the need to satisfy the concerns and requests of these groups can greatly influence the design and manner in which ITS technologies operate in any particular region.

3.7 Support Environment

In general, ITS equipment is installed, operated and maintained at the state or local level. Many of these agencies have their own trained staff, including engineers and electricians to support setup, operation, and maintenance of the equipment; however some rely on outside vendors to support their needs. The numbers and variety of trained personnel is dependent on the quantity and variety of equipment that is fielded, and as such, agencies tend to implement the same technologies and vendor equipment, when possible, across all similar installations.

From an infrastructure perspective, our assumption for the current state would presume an environment already implemented to support the V2I communications described within this section.

Connected vehicle equipment is available from a number of vendors including those who have prequalified their equipment for use in connected vehicle demonstrations, deployments, and tests. This equipment is typically self-installable by the owner/operator of the vehicle. In the case of transit vehicles, trained professional vehicle technicians are usually employed for the installation of the equipment.

Chapter 4 Justification for and Nature of Changes for Mobile Devices in the Connected Vehicle Environment

4.1 Justification for Changes

The majority of the connected vehicle program research to date as it relates to mobile devices has focused on the *vehicle* as the primary generator of the probe messages and safety messages. These messages are defined here as regular or semi-regular messages generated and transmitted without traveler intervention, used to characterize device location and traveler mode to support safety and mobility applications. However, as indicated in the ITS Strategic Plan[13], mobile devices are also an important part of the connected vehicle vision. These include smartphones and other hand-held devices as well as aftermarket devices carried into connected vehicles. The connected vehicle pilot deployment efforts in Tampa, FL and New York City, NY are expected to include a mix of mobile devices and connected vehicle devices, but the potential synergy between the two types of message-generating devices has not been examined.

New messages for mobile devices also have the potential to enable the connected vehicle environment to provide new or improved services and the functionality with those services, to individual travelers in the following ways:

1. Some of these services will enhance existing functions of transit system responses. For example, many transit systems make the locations of trains and buses available on the internet or in response to messages sent by travelers. Adding the traveler's needs and safety aspects to the connected vehicle environment can improve transit system responses.
2. Existing services can be enhanced through the availability of additional data elements and information sharing. For example, walk phases at intersections where handicapped persons frequently cross are often lengthened to provide adequate crossing time. The existing PED-SIG[14] application enables a visually impaired pedestrian to confirm the desired direction of crossing and request a walk signal. A mobile device carried by an individual pedestrian could request a walk phase of a duration appropriate to the walking or rolling speed of that individual. In addition, the intersection could know exactly when the person has finished crossing, rather than having to predict how long to hold the signal.
3. Wholly new functions might be enabled. For example, a transit bus system could reduce the effects of "bus bunching", if it can anticipate the number of passengers at

[13] www.its.dot.gov/strategicplan/

[14] http://www.its.dot.gov/pilots/cv_pilot_apps.htm

stops on heavily traveled routes and dynamically adjust the service levels accordingly.

There is a concern that the addition of mobile devices within the connected vehicle environment as DSRC-enabled connected mobile devices might result in an over-saturation of the channel capacity reducing the overall effectiveness and benefits of the connected vehicle system. In particular, the processing of large numbers of essentially duplicate messages may result in increased latency to identify and process a safety critical message. While the purpose of this project does not include any investigation of channel congestion, the project will however investigate the potential of coordinating message exchanges from mobile devices to other mobile devices and/or vehicles and/or roadside equipment units in order to reduce the number of transmissions. The *Coordination of Mobile Devices for Connected Vehicle Applications* project aims to research potential enhancements of the connected vehicle environment by integrating the *mobile device* into the Connected Vehicle environment in order to facilitate the transmission of personal safety messages (PSM) and personal mobility messages (PMM) that interact with these other system components (i.e.: via P2V and P2I exchange of messages).

4.2 Description of Desired Changes

One of the critical aspects to this project is the concept of “coordination” between devices in a connected vehicle world. In the context of this project, “coordination” refers to the ability of the various devices, both mobile and “carry-in”, to interact and exchange information so that a singular, representative message is presented externally. The three primary objectives of this project and the types of research questions to be answered by this project were described above in Chapter 3 .

4.3 Priorities Among the Changes

Investigating the concepts and implications of introducing mobile devices that are also enabled with DSRC technology into the connected vehicle environment is the top priority among the changes proposed. This includes developing and testing a variety of different scenarios whereby mobile devices are required to coordinate with connected vehicle technology in other mobile devices, vehicles, and infrastructure components. And while it will be also be explored, the impacts of un-coordinated inclusion of these devices cannot be fully considered with the scope of this work. As a secondary consideration, this level of coordination and the introduction of mobile devices themselves presents an opportunity to explore a new class of personal messages and the implications that those messages have for existing connected vehicle and mobile communication standards.

Early research conducted as part of this project revealed the following:

- Specific personal safety and mobility messages do not presently exist in any robust, industry-wide technical specifications or CV deployments, neither domestically nor internationally, even if the definition of the PSM has been included in the to-be-published version of SAE J2735.
- Numerous common mobile device sensor technologies are embedded in mobile devices that could be used for coordinated communication messaging in the connected vehicle environment.
- The inclusion of dedicated short-range communications (DSRC) technology in mobile devices is not widespread nor are any commercial products available.

- There are a number of communication standards that apply to this type of communication, some of which can be utilized for coordination among mobile devices and connected vehicles, others will require new message sets and/or data elements. For example,
  - Message format should be consistent with the ASN.1 notation and terms presently embodied by the previous and the to-be-published versions of the SAE J2735 Message Set Standard.
  - Message content should utilize, to the extent possible, the data elements included in the current BSM and the new PSM message and others as appropriate, but be tailored to meet the goals, objectives, and needs identified within this project.
- Device sensors and communication technologies, including GPS, accelerometers, gyroscopes, proximity sensors, NFC, WiFi, Cellular, Bluetooth, Bluetooth Low Energy are all ubiquitous across the major mobile device brands/suppliers and can be consistently leveraged to assist with the determination of travel state and corresponding transitions.

This project will develop and explore scenarios that will gather information so that an analysis of the impacts of DSRC equipped mobile devices to the connected vehicle environment can be performed, and to gain an understanding of how the current standards, message sets, and assumed operation of mobile devices within the environment may (or may not) need to be modified.

4.4 Changes Considered but not Included

Other applications documented within the CVRIA were considered, but ultimately the “Transit Stop Request” application best represented the necessary framework and considerations for the concepts to be explored under this project. Other transit-related applications such as the “Dynamic Ridesharing,” “Dynamic Transit Operations,” “Integrated Multi-Modal Electronic Payment,” “Transit Connection Protection,” “Transit Vehicle at Station/Stop Warnings,” and others would have provided similar architectural frameworks and were available in the CVRIA, but generally had a more complicated architecture than the “Transit Stop Request.” Because the project is not interested in developing a specific application per se, but rather in testing the message sets and communications protocols, any one of the transit related application architectures could have been selected.

Navigation and trip planning were excluded. Applications that provide these services on mobile devices are currently available. Real-time knowledge of the locations of trains, buses, or traffic is a valuable enhancement to trip planning. New personal mobility messages could certainly play a role in trip planning, but the present scope is to determine the impacts on single nodes or links in the process, not the entire trip per se; however, information from back-office applications such as TMCs/TOCs and/or TrMCs are considered to a certain extent. A transit operator may respond to a PMM if it is unable to promptly fulfill a travel request (for example, because a bus has broken down or its bicycle carrier is full), but decisions about possible alternative routes is not part of this research project.

The messages are not intended to be limited to specific situations or travelers’ needs. However, the concepts are described in the context of a metropolitan environment, where many individual travelers exist. Extended trips on intercity highways are excluded from this research project.

4.5 Assumptions and Constraints

The intent is not to develop new hardware or communication methods, but rather to investigate how new messages and the existing standards, hardware, and communication functions within mobile devices can be leveraged to provide a coordinated approach for communication. As such, the following is assumed:

- Any new messages will conform to the general format of SAE J2735 and will be consistent with existing connected vehicle standards.
- Any BSM message exchanges will conform generally to the performance requirements for BSM message broadcast defined in SAE 2945/9.
- The project will utilize available DSRC hardware and communications protocols for low-latency messages.
- The project will utilize available mobile devices capable of supporting cellular, WiFi, and Bluetooth communications.
- The demonstrated system is not intended to become a stand-alone connected vehicle application, but rather a series of smaller portions of software code that are designed to specifically address the research questions and objectives of this project through experimentation and testing.

Chapter 5 Concepts for the Proposed System

5.1 Background, Objectives, and Scope

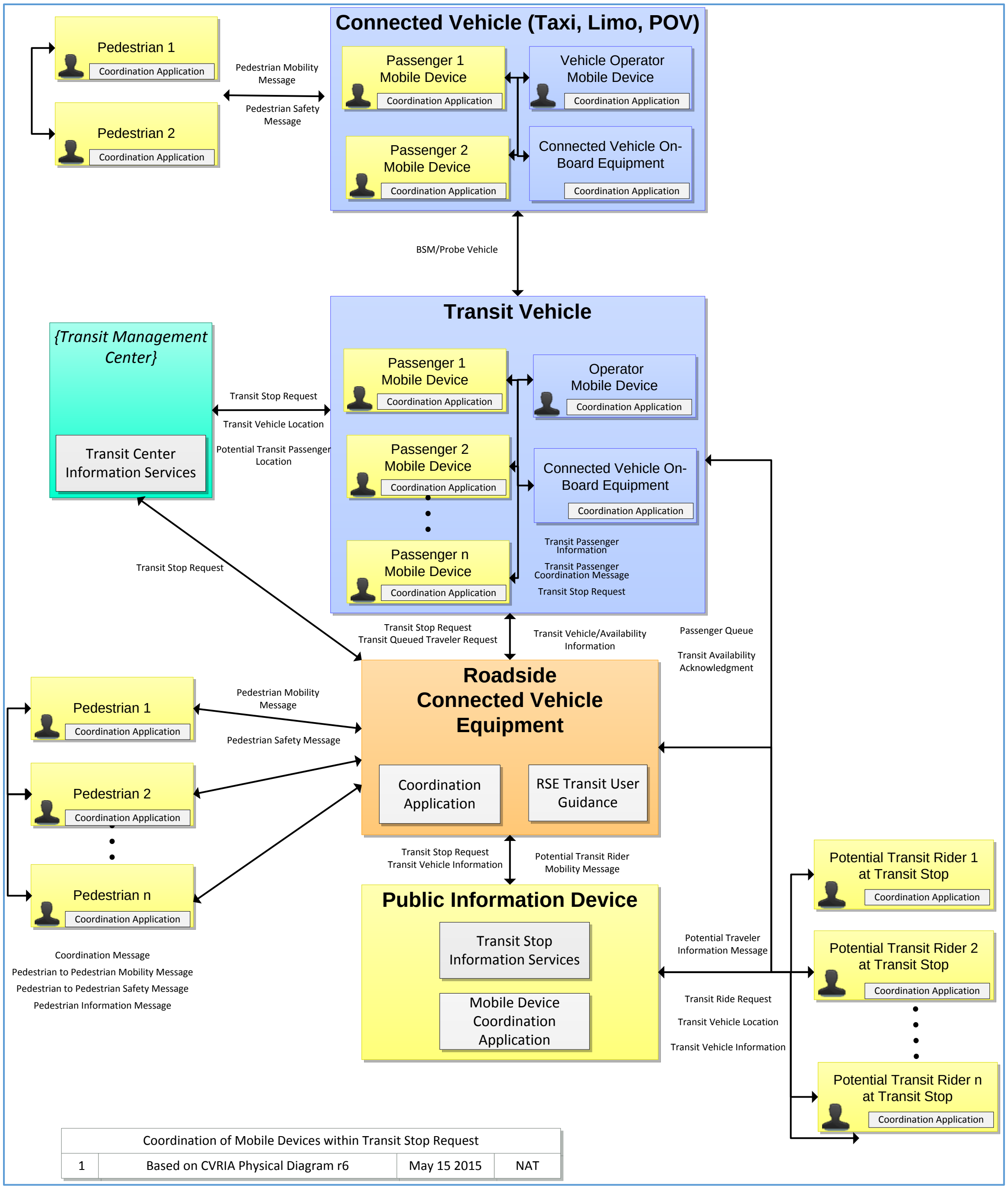
The proposed system builds on the current system, with the significant difference in that the proposed system includes and demonstrates the benefits/impacts of both coordinated and uncoordinated use of DSRC-equipped mobile devices.

There are a number of research questions to be investigated and addressed in this project. Although this will be accomplished through use of an application defined in the CVRIA, the intent is not to develop a deployable application but rather to capture information under a wide variety of different circumstances that will help U.S. DOT and other stakeholders with the ability to answer questions such as:

1. Can the mobile device and connected vehicle technology switch between DSRC, cellular, and WiFi without service interruption?
2. Is the inherent latency between communication transfers sufficiently small?
3. Are there significant differences in the communication or message protocols that impact delivery of the information?
4. Is there a significant difference in the amount and number of messages received between coordinated and uncoordinated messages?

One objective of the project is to investigate and alleviate the potential for oversaturation of the connected vehicle environment from extraneous and effectively duplicate messages. In particular, it would be desirable to refine and separate the routine broadcasting of position information dynamically between high- and low- latency communication protocols. For example, under conditions where real-time positional information is not critical, a connected device would utilize a higher latency communication pathway such as cellular and/or WiFi but would dynamically switch to a low-latency protocol such as DSRC when needed.

For simplicity, the conceptual system described in this document expands upon the existing “Transit Stop Request” application defined in the CVRIA to accommodate the coordination of multiple mobile devices across different scenarios. As such, the proposed concept, shown below in Figure 5-1, adds the coordination between mobile devices (P2P), mobile devices and a vehicle (P2V), and coordination between mobile devices and an infrastructure component (P2I) to the existing SET-IT “Transit Stop Request” application diagram (see Figure 3-2 above). These various combinations are expressed through multiple pedestrians, transit passengers, potential transit riders, passengers and drivers in connected vehicles in yellow-boxes with a “Coordination Application” that resides within a mobile device responsible for providing the coordination.



Source: Battelle based upon Original SET-IT Architecture Diagram

Figure 5-1. High-Level CVRIA-based Application Diagram and Components being Utilized to Examine Coordination of Mobile Devices

5.2 Operational Policies and Constraints

Mobile devices must be brought to the connected vehicle environment based on value propositions for their inclusion, while at the same time, having minimal impact on the current architectures and standards. The CV environment system works already because the vast number of players, government at various levels, and numerous private companies do adhere to the existing data exchange interface standards. Only those changes directly necessary for coordination of the mobile devices should be considered in an expanded CV environment.

Costs for infrastructure components are borne by government entities and are not directly seen by individuals. Costs for hardware components in personal vehicles are part of the overall cost of the vehicle and these hardware components will be on all vehicles if their presence is mandated (note that the anticipated mandate to install DSRC hardware components will be limited to software supporting the broadcasting BSM messages; all other message types might or might not be present in vehicles dependent on vehicle manufacturer's economic decisions). Any increased cost to an individual mobile device must be negligible so that consumers can accept it. If the capability of DSRC, for example, is an option, then it must be perceived as providing benefits that are readily obtained by consumers and far outweigh the costs.

Size, weight, and power availability on hand-held mobile devices are significantly constrained beyond those of vehicle-based systems. Implementation of low-latency DSRC to enable PSM/PMM capability will likely impact the overall utility of the mobile device in both physical dimensions as well as electrical capabilities, particularly processing availability and battery life. This will impose operational constraints on the testing and experiments to ensure that data can be collected continuously and without loss.

The following are the different levels of notification that will be sent to users in this ConOps:

- Advisory Messages are issued when a pedestrian is in the area. This is the lowest level of notification to the user.
- Alert Messages are issued when a driver must take action to avoid a potential collision with a pedestrian. The distance at which an Alert message is displayed is determined by the stopping distance equation and the standard (design) braking force.
- Warning Messages are issued when a driver must take immediate action to nearly avoid a collision with a pedestrian or mitigate its impact. The distance at which a Warning message is displayed is determined by the stopping distance equation and the maximum braking force. This is the highest level of notification.

The distance at which an advisory, alert, or warning is displayed to a driver or a vulnerable road user is based on vehicle stopping distance, explained in 9.3Appendix C.

The concepts discussed in this document apply real-world scenarios to provide the necessary context of the objectives. The technology systems to be developed as part of this project address a subset of the user needs defined in this document and will demonstrate the proposed real-world scenarios, which may not be scalable or deployable beyond the demonstrations, but are rather specifically tailored for the demonstration (i.e., simplified software applications to elicit a particular interaction or event).

5.3 Descriptions of the Proposed System

Coordinated mobile devices potentially expand the capability of the current CV environment and enhance its benefits. An expanded CV environment to accommodate mobile devices is being proposed to include existing and new types of messages; such as a Personal Safety Message (PSM – existing within the March 2016-published version of SAE J2735), a Personal Mobility Message (PMM), and a variety of coordination messages. The J2735-defined PSM transmits a pedestrian's position, speed, and heading, among other information; however, part of this research project is to investigate whether the PSM message defined in the new draft J2735 standard is sufficient or should be expanded based on the findings of this project. Surrounding vehicles will be able to use this information provided via received PSMs in various applications to avoid collisions. The PSM will notify vehicles of the presence, for example, of a pedestrian in a crosswalk or of a runner in the street. New applications could be written for the vehicle platforms so their drivers are aware of foot traffic. This can have benefits, for example, at roundabouts, where drivers must look for targets in many locations. It can reduce injuries in situations where drivers look left while they turn right on red.

The PMM will enable new applications benefitting a variety of users. It is expected to contain information about the traveler's next intended movement and/or their requirements for travel such as schedule constraints, mobility issues, etc. A movement may be to cross a street, board a bus, or find a shared vehicle. The PMM will also contain information about the constraints on the traveler's trip such as requiring a transit vehicle with a wheelchair lift.

Coordination messages will allow mobile devices to directly and efficiently communicate with each other at a "local level" for the purposes of reducing the overall communication burden to the transportation system. In particular, these coordination messages will be used to temporarily "link" travelers together into groups so that only a single message regarding the group needs to be sent to an infrastructure or vehicle component rather than individual messages from every member of the group.

As discussed in the Task 2 Report[15], most current mobile devices do not inherently include a specific chipset that is dedicated to DSRC enabling technology. Some hardware components and/or DSRC-communications-specific firmware adjustments will be needed to either retune an 802.11 WiFi chip to the 5.9 GHz spectrum, or secondary aftermarket "backpacks" or plug-ins will be required. The major development of coordinated mobile devices will be in the interface between mobile devices and the existing system and the exchange of messages between these devices and the existing connected vehicle equipment for coordination and for additional safety and mobility applications.

5.4 Modes of Operation

The proposed system will be utilized in small-scale demonstrations 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, passenger vehicles, or travelers.

[15] "Conduct Scan of Technology, Application Standards, and Stakeholder Engagement," Draft Final Report, Battelle, 2015, Contract Number: DTFH61-12-D-00046

There will be several different modes of operation during each demonstration, which will be guided by an experimental design. These modes are expected to include:

- **Completely Uncoordinated** – In this mode, all mobile devices involved in the demonstrations will be operating independently from each other and from connected vehicles.
- **Fully Coordinated** – In this mode, all of the mobile devices involved in the demonstrations will be interacting and exchanging messages and information with each other, infrastructure components, RSEs and connected vehicles.

5.5 Proposed System User Classes and Other Involved Personnel

The user classes and associated personnel are expected to remain the same as in the existing CV environment as detailed in Chapter 3 . However, the proposed system highlights pedestrians with mobile devices as a primary user class; further subdivided into whether they are operating in a coordinated or uncoordinated fashion. Additionally, the proposed system considers the transition of a mobile device user from pedestrian to transit passenger (or shared vehicle passenger, i.e., taxi).

In the experiments tested within the small-scale demonstration, Battelle staff will serve in each of these roles.

In the large-scale demonstration, Battelle will serve as the infrastructure provider while a university campus bus service will provide drivers and vehicles. Staff working on the university campus will be recruited to be travelers using mobile devices and interacting with vehicle and infrastructure systems.

5.6 Support Environment

The proposed system will operate within the connected vehicle environment using existing and emerging versions of interface standards such as SAE J2735 that are routinely utilized within the connected vehicle environment.

A small scale demonstration with several individual experiments will be conducted at FHWA's Turner-Fairbank Highway Research Center in Northern Virginia, if the location is determined to be suitable – otherwise, in a nearby location in the Washington, DC metropolitan area. A combination of mobile devices, transit vehicles, and passenger automobiles will be used for the small-scale tests. The experimental tests executed during the small-scale demonstration is anticipated to include both RSEs, transit vehicles, personal automobiles, and pedestrians/passengers with mobile devices.

The large-scale demonstration will be conducted in a naturalistic setting using a university's transit vehicles. The demonstration will be centered around the on-campus facility. Connected vehicle equipment for the transit vehicles and infrastructure components will be provided and installed by Battelle staff. DSRC equipped mobile devices will be supplied to participants by Battelle.

Chapter 6 User Needs

This section lists user needs to be addressed during the execution of the small-scale and large-scale demonstration tests (see Operational Scenarios in Chapter 7) and are derived from the previous chapters and within the Operational Scenarios in Chapter 7 within the ConOps. The following is a listing of the user needs with assigned unique user need identification numbers, a user need title, and a description of the user need.

The user needs will be mapped to system requirements within the 'Needs to Requirements Traceability Matrix' defined in the System Requirements document to ensure that each user need has at least one requirement that will fulfill each of the user needs.

Note 1: Gaps in User Need ID numbering are intentional to allow for potential addition of needs as more experiences are gained within the demonstrations.
Note 2: The distance at which an advisory, alert, or warning is displayed to a driver or a vulnerable road user is based on vehicle stopping distance, explained in 9.3Appendix C.
Note 3: Mobile Device-carrying vulnerable road users include pedestrians and people with disabilities including wheelchair-bound users, and the term 'pedestrian' in the User Need Title stands as representative for these types of vulnerable road users.

Table 6.1: User Needs Definition Table

User Need ID	User Need Title	User Need
UN 1.0	Driver and Pedestrian Warning / Alert Reception Needs	
UN 1.01	Driver Advisory of Pedestrians in Area	A driver needs to be advised when pedestrians are present. See Appendix C for distance at which an Advisory is displayed.
UN 1.02	Driver Alerts of Pedestrians in Unsafe Zone	A driver needs to be alerted when pedestrians are within the approaching vehicle's trajectory and are located in an unsafe zone. See Appendix C for distance at which an Advisory is displayed. *Note: An "Unsafe Zone" is an area in which a pedestrian is vulnerable to other transportation devices, such as when a pedestrian is the lane of travel or the part of the roadway shoulder closest to the travel lane of a vehicle or when in a roadway crosswalk. The area in which the user is located is NOT considered an unsafe zone unless there is a DSRC-equipped vehicle present which could potentially cause harm to a mobile-device-carrying user.*
UN 1.03	Driver Warning of Pedestrians in Travel Lane	A driver needs to be warned when pedestrians are within the approaching vehicle's trajectory and are in the vehicle's lane of travel. See Appendix C for distance at which an Advisory is displayed.
UN 1.04	Driver Warning of Pedestrian in Crosswalk without permissive Pedestrian Indication	An approaching driver must be warned when a pedestrian is crossing against the signal.

User Need ID	User Need Title	User Need
UN 1.11	Pedestrian Advisory of vehicles Approaching	A pedestrian needs to be advised, if they are within an approaching vehicle's trajectory. See Appendix C for distance at which an Advisory is displayed.
UN 1.12	Pedestrian Alert of approaching vehicles when in unsafe zone	A pedestrian needs to be alerted if they are within an approaching vehicle's trajectory and the pedestrian is in an unsafe zone. See Appendix C for distance at which an Advisory is displayed.
UN 1.13	Mobile Device user Warning of vehicle approaching when in Travel Lane	A pedestrian needs to be warned if they are within an approaching vehicle's trajectory and the pedestrian is in the vehicle's lane of travel. See Appendix C for distance at which an Advisory is displayed.
UN 1.14	Warning of Pedestrian when entering a signalized crosswalk during Don't Walk times	A pedestrian must be warned when he/she is crossing against the signal, i.e., the WALK indication of the crossing to be taken by the pedestrian is not on.
UN 2.0	Mobile Device and In-Vehicle Device Warning / Alert Generation Needs	
UN 2.01	Driver Receipt of Advisories, Alerts, and Warnings independent of device placement on person	A driver needs to be notified of advisories, alerts, and warnings based on Personal Safety Messages (PSMs) received from a pedestrian's mobile device regardless of where that mobile device is located on a pedestrian's person or exterior to her/his clothing and purse/briefcase. *Note: PSM are Personal Safety Messages transmitted by mobile devices, where a PSM is similar to a Basic Safety Message (BSM) transmitted by a vehicle but tailored to the safety needs of vulnerable road users. A PSM is intended to transmit low-latency, urgent safety messages between individual travelers and vehicles/infrastructure, via a mobile device*
UN 2.02	Pedestrian Receipt of Advisories, Alerts, and Warnings independent of device placement on person	A pedestrian needs to be notified of advisories, alerts, and warnings based on BSMs (or Surrogate BSMs) received from a vehicle regardless of where the mobile device is located on the pedestrian's person or exterior to her/his clothing and purse/briefcase. *Note: 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 whether vehicle-internal equipment such as wipers are turned on or off..*
UN 2.03	Driver Receipt of Advisories, Alerts, and Warnings independent of device placement on wheelchair	A driver needs to be notified of advisories, alerts, and warnings based on PSMs received from a Wheelchair user's mobile device regardless of where the mobile device is located on the traveler's wheelchair.
UN 2.04	Wheelchair-bound Person Receipt of Advisories, Alerts, and Warnings independent on device placement on wheelchair	A wheelchair-bound person be notified of advisories, alerts, and warnings based on BSMs (or Surrogate BSMs) received from a vehicle regardless of where the mobile device is located on the travelers wheelchair.
UN 2.05	Pedestrian in Crosswalk Detection	An intersection RSE must be able to detect when a pedestrian with an equipped mobile device is located in a crosswalk. It also must know which crosswalk the pedestrian is in and update SPaT messages, MAP messages, and issue/cease pedestrian and driver warnings accordingly.

User Need ID	User Need Title	User Need
UN 3.0	Mobile Device in Vehicle Location Detection Needs	
UN 3.01	Detection of Passenger within Light Duty Vehicle	A user of a mobile device needs to be detected if s/he becomes a passenger embarking a light duty vehicle. *Note: Detection may be different for different vehicle types.*
UN 3.02	Detection of Passenger disembarking Light Duty Vehicle	A user of a mobile device needs to be detected if s/he is disembarking a light duty vehicle. *Note: Detection may be different for different vehicle types.*
UN 3.03	Detection of Passenger within Transit Vehicle	A user of a mobile device needs to be detected if s/he becomes a passenger embarking a transit vehicle.
UN 3.04	Detection of Passenger disembarking Transit Vehicle	A user of a mobile device needs to be detected if s/he is disembarking a transit vehicle.
UN 3.05	Location within virtual digital intersection map.	A user of a mobile device must be detected when he/she is in the vicinity of an intersection and which pedestrian crossings he/she is closest to.
UN 4.0	Mobile Device User / Vehicle Travel Coordination Needs	
UN 4.01	Send travel / ride request message (PMM)	A user of a mobile device needs to be able to send travel / ride requests including desired departure time, departure location, destination, number of travelers in travel group, and mobility needs to a selected entity (taxi, ride-share, or transit) from any location (regardless whether in range of a DSRC-capable device or not). A ride/travel request message will be send in form of a personal mobility message (PMM)
UN 4.02	Update travel / ride request message (PMM)	A user of a mobile device needs to be able to update travel / ride requests including desired departure time, departure location, destination, number of travelers in travel group, and mobility needs from any location (regardless whether in range of a DSRC-capable device or not).
UN 4.03	Receive travel / ride request acknowledgement	A user of a mobile device needs to be able to receive travel / ride request acknowledgements from a vehicle confirming that s/he is being picked up at any location (regardless whether in range of a DSRC-capable device or not).
UN 4.04	Stop sending travel / ride requests (PMMs)	A user of a mobile device needs to stop sending travel / ride requests manually or automatically from any location (regardless whether in range of a DSRC-capable device or not) as soon as the corresponding acknowledgement has been received.
UN 4.06	Cancelling travel / ride requests (PMM Cancel)	A user of a mobile device needs to be able to cancel travel / ride requests manually or automatically from any location (regardless whether in range of a DSRC-capable device or not): - Manually, if the user decides to cancel the intended trip - Automatically, when a pedestrian's mobile device becomes part of a larger ad-hoc travel group.
UN 4.05	Resume PSM broadcasting	A user of a mobile device needs to be ensured that the mobile device resumes broadcasting PSMs when s/he disembarks a vehicle (again becoming a pedestrian versus being a passenger). *Note: See UN 5.05 for stopping PSM broadcasting when embarking a vehicle.*

User Need ID	User Need Title	User Need
UN 4.11	Receive travel / ride request message	A driver of a transit vehicle needs to be able to receive travel / ride requests including desired departure time, departure location, destination, number of travelers in travel group, and mobility needs from a mobile device from any location (regardless whether in range of a DSRC-capable device or not).
UN 4.12	Receive travel / ride request Update message	A driver of a transit vehicle needs to be able to receive updated travel / ride requests including desired departure time, departure location, destination, number of travelers in travel group, and mobility needs from a mobile device from any location (regardless whether in range of a DSRC-capable device or not).
UN 4.13	Send travel / ride request acknowledgement	A driver of a transit vehicle needs to be able to send travel / ride request acknowledgements to the user of a mobile device confirming that s/he is being picked up.
UN 4.15	Maintain communications when switching from one communications media to another	A user of a mobile device needs to maintain the current active 'session' with vehicles and other mobile devices when their mobile device switches from one communications media to another.
UN 4.20	Disembarkment Notification	A user of a mobile device must receive a message from a transit vehicle prior to arriving to the disembarkment location to indicate to the passenger when to exit.
UN 4.21	Receive signalized intersection information	A user of a mobile device must be able to receive signal phase and timing information from a signalized intersection s/he is approaching.
UN 4.22	Request to use Crosswalk	A user of a mobile device must be able to indicate to a signalized intersection which crosswalk s/he intends to use.
UN 4.23	Receive Traveler information	A mobile device must be able to receive traveler information (e.g. weather information, car sharing services, bike share availability, etc.) updates at regular intervals from various sources including DSRC-equipped vehicles, RSEs, and webpages. *Note: No existing J2735-like message standard defines these types of messages. And the J2735-defined Traveler Information Message (TIM) is designed to provide information only from a vehicle to a roadside equipment unit (RSE), where the weather-related message content is collected by the vehicle.*
UN 5.0	Mobile Device User Travel Group Coordination Needs	
UN 5.01	Creation of ad-hoc travel groups	Users of mobile devices need to be able to dynamically create ad-hoc travel groups with other mobile device users, if their departure time, departure location, and destination are the same. The creation of ad-hoc travel groups might be accomplished using different technologies and/or be distance-based or signal-strength-based. *Note1: an ad-hoc travel group is a group of travelers formed automatically via mobile device-to-mobile device communications, when ride / travel requesters have entered the same travel / ride request information in terms of departure location, departure time, and destination location.*

User Need ID	User Need Title	User Need
		Note2: For the Experimental Prototype System (EPS), travel groups are only formed and maintained when travelers are within proximity of the pickup location.
UN 5.02	Transmit ad-hoc travel group travel / ride requests	Users combined into an ad-hoc travel group need to transmit a combined travel / ride request messages.
UN 5.03	Receive travel / ride request acknowledgement while in travel group	Users combined into an ad-hoc travel group need to receive a travel / ride request acknowledgement from a vehicle confirming that the group is being picked up.
UN 5.04	Stop sending travel / ride request messages when entering vehicle	Users combined into an ad-hoc travel group need to stop sending travel / ride request messages when they enter a vehicle.
UN 5.05	Stop sending personal safety messages when entering equipped vehicle	Users combined into an ad-hoc, dynamic travel group need to stop transmitting joint personal safety messages, when they enter a vehicle that sends vehicle-specific basic safety messages.
UN 5.06	Leaving ad-hoc travel group	A user of a mobile device needs to be able to leave an ad-hoc travel group. This might happen, if a user actively changes its departure time and/or location, its destination location, or if the ad-hoc group dissolves upon entering a vehicle.
UN 6.0	Mobile Device Acting as Vehicle Message Provider Needs	
UN 6.01	Sending individual Surrogate BSMs	In order to satisfy their personal safety needs, a user of a mobile device located in an unequipped vehicle (a vehicle that does not broadcast basic safety messages via DSRC) needs to broadcast “Surrogate BSM”s on behalf of the unequipped vehicle. *Surrogate BSMs are messages broadcasted by a mobile device that provide X/Y location, heading and speed information as a minimum as well as an indicator that the mobile device is in a vehicle (based on speed, acceleration, and potentially other parameters).*
UN 6.02	Stop sending Surrogate BSMs	A user of a mobile device needs to stop sending “Surrogate BSM” messages, when s/he exits an unequipped vehicle.
UN 6.03	Receiving Surrogate BSMs	A driver (of other surrounding vehicles) needs to receive “Surrogate BSM” messages sent from mobile devices within vehicles that do not have on-board DSRC equipment to send BSMs.
UN 7.0	Mobile Device Performance Needs	
UN 7.01	Alert/Warning display within 0.5 seconds from message receipt	A users of a mobile device needs to receive advisories, alert, and warnings on their mobile device within 0.5 seconds after receiving a message within the mobile device. *Note: Advisories, alerts, and warnings might be conveyed to a user via audible, haptic, screen displayed, or combination means.*
UN 7.02	Location detection accuracy	A users of a mobile device needs to be detected if s/he is in a safe or unsafe zone within 50 centimeter accuracy. *Note: the Battelle Team is currently assessing the tradeoff between positioning accuracy and sensitivity/specificity of collision prediction.*
UN 7.03	Mobile Device Communications from an ad-hoc travel group not interfering with communications	Users of mobile devices having combined into an ad-hoc travel group have the need that their communications do not interfere with the communications from other nearby mobile devices and/or other

User Need ID	User Need Title	User Need
	by other travelers or other travel groups	nearby ad-hoc travel groups with different departure times, departure locations, and/or destinations.
UN 8.0	System Monitoring Needs	
UN 8.01	Logging of all messages sent and received	The EPS needs to capture and log time and content of all messages sent to and from each mobile device and each vehicle being part of the EPS.
UN 8.02	Logging of all messages displayed on a device screen	The EPS needs to capture and log the time and content of all information being displayed on each mobile device screen and each vehicle screen being part of the EPS.
UN 8.03	Provision of Reliable Equipment (Vehicles, Mobile Devices, Roadside Equipment, Cloud Infrastructure)	The EPS needs to be designed and deployed with reliable equipment within the vehicles (passenger / light duty vehicles), mobile devices, roadside equipment, and cloud infrastructure equipment in order to last for the duration of the demonstration, as a minimum.
UN 8.04	Message Display/Notification	The RSE must include a message display/notification feature via the screen of the data collection equipment that captures the message exchanges.

Source: Battelle

Chapter 7 Operational Scenarios

This section describes different conceptual scenarios that enumerate actions, tasks, activities, communication between mobile devices, vehicles, and infrastructure to illustrate and investigate the feasibility of coordination of messages between mobile devices and connected vehicle elements. The first set of three scenarios are designed for a small-scale demonstration environment and focus on:

1. Exploring communication methods for personal safety and personal mobility messages (PSMs and PMMs).
2. Exploring the feasibility/impact of dynamically switching between the communications media.
3. The impact of “coordinated” and “uncoordinated” message exchanges between mobile devices and connected vehicles.

The second set of operational scenarios are designed to demonstrate the coordination of mobile devices and connected vehicles on a larger scale and under more complex travel environments and are intended to be conducted as a naturalistic study. These scenarios will focus on trip mode transitions and a set of messages that will be needed to incorporate mobile devices into the connected vehicle environment.

Both sets of scenarios provide for opportunities to examine the existing standards and message sets for use by mobile devices and will provide information on the potential impact of connected mobile devices in the connected vehicle environment.

Table 7.1, Small-Scale Scenarios, summarizes a set of three operational scenarios whose essence will be performed within the small-scale demonstration. The small-scale scenarios are expected to be performed in a controlled field environment (e.g., the Turner-Fairbank Highway Research Center). The concept is that each of the scenarios will progress in complexity once baseline functionality has been investigated and demonstrated. Each step in the scenarios have been formulated to capture specific topics and data of particular interest.

Table 7.1. Summary of the Set of Operational Scenarios for the Small-Scale Demonstration

No.	Demonstrated Real-World Example	Summary	Objective(s)
1	Multiple pedestrians engaging in taxi, ride-sharing, or other car/limo services along a street	Multiple travelers use mobile device to "book a ride" and board/disembark. Travelers broadcast individual mobility and safety messages to connected vehicles during this transfer.	1) Illustrate coordinated and uncoordinated traveler/vehicle communication. 2) Illustrate individual traveler safety and mobility messages
2	Large crowd, special event transit service (shuttle bus)	A large crowd of travelers clusters at two "pickup" locations waiting for two partially full transit vehicles to provide shuttle service.	Illustrate benefits of coordination during situations where channel capacity limitations are prevalent
3	Transit and Paratransit service along a corridor	Two transit vehicles (one paratransit) travel along a road segment picking up and dropping off passengers.	Illustrate coordinated and uncoordinated mobile devices interacting with transit vehicles and infrastructure components.
4	Pedestrians sending and receiving signalized intersection-related data	Pedestrian approaches intersection and issues WALK request and receives Phase timing information. Traffic signal controller sending indication of pedestrian in crosswalk information to approaching vehicles.	1. Illustrate how a mobile device can request a WALK signal without pressing a walk-request button. 2. Illustrate how a traffic signal controller can send the presence of a pedestrian in the crosswalk to approaching vehicles.

Source: Battelle

7.1 Small-Scale Scenario 1 – Multiple Travelers in Multiple Light-Vehicles Boarding and Disembarking Mid-Block, No RSE Present

7.1.1 Small-Scale Scenario 1 – Objective, Summary, and Relation to Real-World Event

This scenario is based upon the real-world events associated with travelers utilizing taxi, ridesharing, paratransit, and other services to transition from a pedestrian to a vehicle occupant in a light-duty passenger vehicle. Specific interactions and events included in this scenario are:

1. Personal Mobility Message (PMM) exchange for ride request and pickup.
2. Personal Safety Message (PSM) exchange for pedestrian in the street to include rapid (i.e., without significant lag) and dynamic switching (i.e., without user interaction) from cellular-based to DSRC-based communications methods if the surrounding conditions require low-latency communications to enhance safety.

3. PMM exchange of travel, mobility needs, and other information between passenger and driver in a non-connected vehicle.
4. PMM coordination of mobile devices between passengers and a connected vehicle.
5. PSM coordination of mobile devices between pedestrians waiting for the same transit bus.

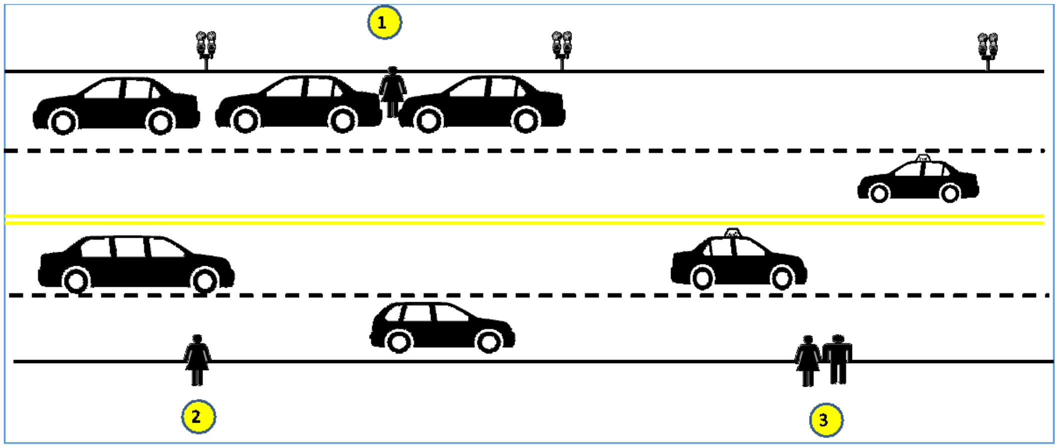
Travelers waiting for taxi and/or rideshare (or paratransit) pickup occur daily in virtually all major cities and represent a potential segment of travelers that, by providing individual safety messages to other connected vehicles, may reduce the risk of being struck by an oncoming vehicle. Similarly, providing an individual traveler mobility message such as indicating travel needs, requirements, etc. may enhance the mobility of the traveler. For example, a traveler who desires to rideshare may broadcast their desire to go to the airport, which if received by the driver of a connected vehicle would result in the traveler being accommodated by the driver so that the driver of the vehicle could take advantage of HOV/HOT lanes instead of general purpose lanes (i.e., “slugging”).

7.1.2 Small-Scale Scenario 1 – Prerequisites and Scenario Conditions

The following summarizes the prerequisites and scenario conditions

- This scenario is envisioned to simulate an urban setting along a street that is congested with parked vehicles on either side of the street.
- Travelers arranging for pick-up and drop-off will do so at various points along the road segment, including waiting for a pick-up between two stopped vehicles, crossing the street mid-block to catch a vehicle waiting on the other side for a pickup.
- The scenario will be assumed to occur in good visibility during daylight hours.
- There are assumed to be two connected vehicles (one car, one bus) and one non-connected vehicle (car) on the road segment. Connected vehicles refer to those with DSRC equipment installed and operational.
- This scenario assumes that travelers have mobile devices that are capable of communicating through a number of different technologies including WiFi, Bluetooth, cellular, and DSRC.
- Cellular coverage and GPS is available to all vehicles and travelers.
- All mobile devices and vehicle communications equipment is fully functional.

Figure 7-1 provides a high-level illustration of this conceptual scenario that encompasses these conditions and prerequisites. As illustrated in the figure, multiple travelers will be expected to engage in obtaining vehicle rides at mid-block locations under good visibility and experimentally fixed mobility conditions. Indicated in the figure by the yellow “1”, a traveler waits for a connected vehicle taxi while standing between two parked vehicles. Indicator “2” depicts a traveler waiting for a connected vehicle limo. “3” depicts two separate travelers waiting in the same geographic location for their non-connected vehicle rideshare vehicle.



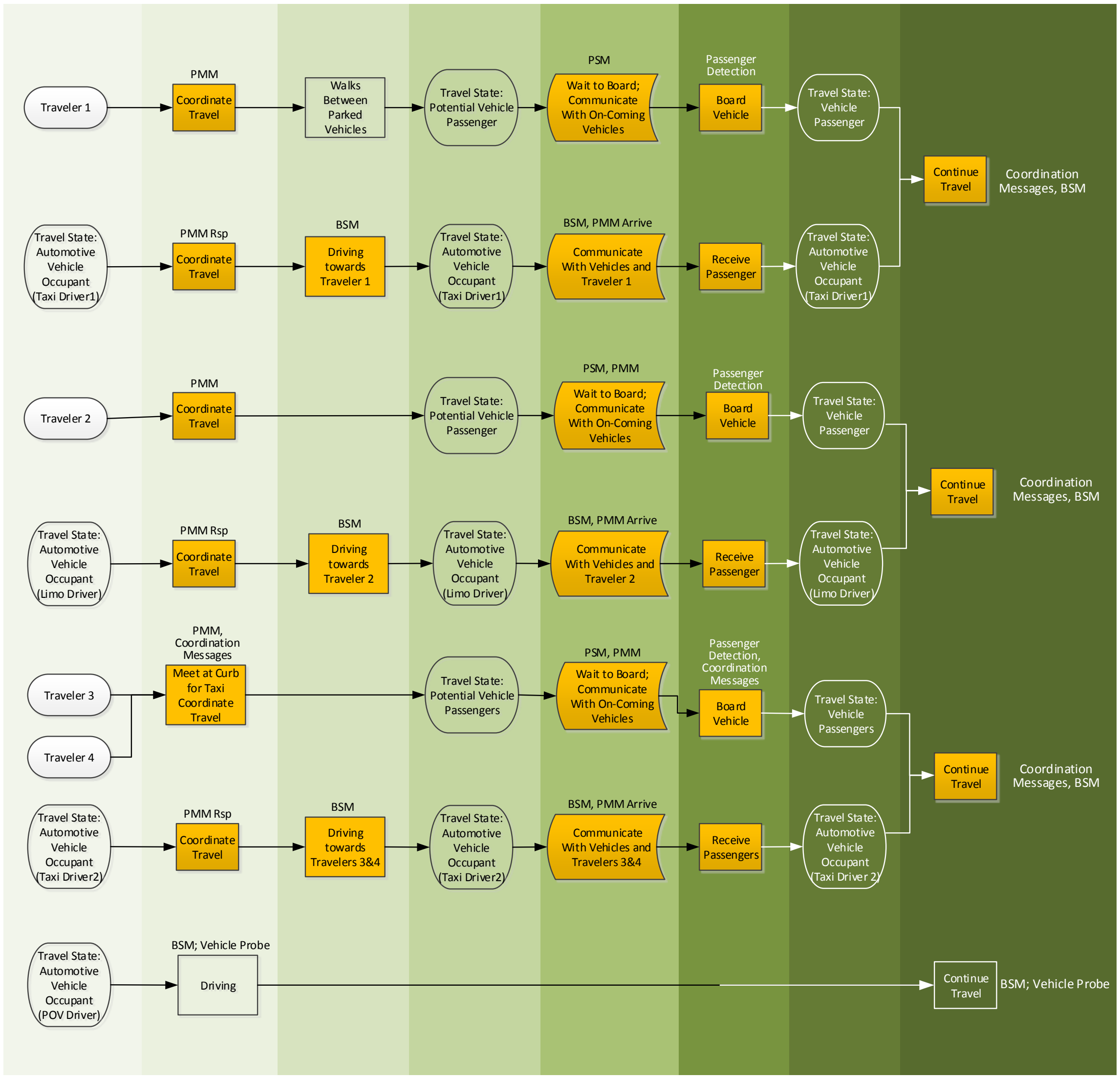
Source: Battelle

Figure 7-1. Graphical Representation of the Scenario Conditions for Small-Scale Scenario 1

7.1.3 Small Scale Scenario 1 – Description of Events/Process

This scenario has a short sequence of events but with numerous opportunities for coordination of mobile devices with each other and with connected vehicles. All four travelers are assumed to be seeking a ride in a taxi or limo with various other personal automobiles equipped with connected vehicle technology randomly passing through the road segment throughout the duration of the scenario. For the purpose of describing the events and process, the following assumes only one personal automobile active during the scenario though in reality there could be any number of connected and non-connected vehicles.

Figure 7-2 is provided to assist the reader in understanding the intended simultaneous nature of the sequence of events that are anticipated to occur in this scenario. In the figure, the vertical bands with a progression of darker shades of green are meant to convey time intervals. All events that appear in the same vertical band are assumed to occur during that time interval.



Source: Battelle

Figure 7-2. Time-Phased Sequence of Events for Scenario 1

For readability however, the events and messages for each set of travelers are separately enumerated sequentially.

Pedestrian 1 – DSRC and Cellular Equipped Taxi 1:

1. A pedestrian with a DSRC-equipped mobile device, uses a connected vehicle application on a mobile device to order a taxi.
2. The application on the mobile device sends a Personal Mobility Message (PMM) to a Ride Request Database Service via cellular communications. This request includes:
    a. A request ID (randomly generated identifier):
    b. Transport Preference: Taxi
    c. Number of Travelers: 1
    d. Mobility Requirements: none
    e. Departure Time: Now
    f. Origin: Current location (latitude, longitude)
    g. Destination: Desired location (latitude, longitude)
3. Either a Taxi Provider receives the PMMs from the Ride Request Database Service and coordinates with a taxi in its fleet, or a taxi receives the PMM directly.
4. An acknowledgement of a taxi request is sent to the mobile device.
5. The mobile device continues to provide and receive location updates to and from the responding taxi via cellular:
    a. Location (Latitude, Longitude, Timestamp) (similar information on the taxi's location is provided from the taxi)
    b. Request ID
6. The pedestrian walks between parked vehicles to try and spot the on-coming taxi.
7. The mobile device determines that the pedestrian has entered a safety zone and switches to broadcasting a Personal Safety Message (PSM) with the following information at regular, pre-defined intervals:
    a. Location (Latitude, Longitude, Timestamp)
    b. A warning to on-coming vehicles that she is in a safety restricted space (e.g., on the road in a parking zone)
8. The mobile device receives BSM and Vehicle Probe Messages from on-coming vehicles alerting/warning the woman, if there is a vehicle approaching at a high-rate of speed in the lane closest to her.
9. The responding taxi driving towards the ride-requesting mobile device receives the request for a pickup via cellular communications and begins to broadcast its location to the ride-requesting mobile device.
10. The taxi proceeds towards the pedestrian until within DSRC range. The taxi switches to DSRC communications at 1 second (or faster) intervals and broadcasts:
    a. BSM/Vehicle Probe
    b. Acknowledgement of the Request ID
11. The ride-requesting mobile device determines that the taxi is within DSRC range and switches to broadcasting PMMs at 10 second intervals (or faster intervals) with her location and Request ID.

12. As the taxi approaches the ride-requesting mobile device, the taxi continuously updates the driver and the ride-requesting mobile device using PMM DSRC messages of their respective location.
13. The taxi driver identifies the ride-requesting user by location and through personal, human interaction and pulls over to the side of the road.
14. The ride-requesting user boards the taxi.
15. The ride-requesting mobile device mobile device detects that it has entered a vehicle. As a result of this detection, the ride-requesting mobile device mobile device ceases to broadcast PMM messages via DSRC.
16. The taxi, with the passenger, continues on the trip broadcasting only BSM and Vehicle Probe Messages using the vehicle's DSRC equipment.
17. The taxi exchanges BSM and Vehicle Probe Messages with other connected vehicles.

Pedestrian 2, Limo Without Connected Vehicle Technology

1. A pedestrian with a DSRC-equipped mobile device uses a connected vehicle application on the mobile device to indicate that the user is seeking a taxi.
2. The application on the ride-requesting mobile device sends a Personal Mobility Message (PMM) to a Ride Request Database Service via cellular communications. This request includes:
    a. A request ID (randomly generated identifier):
    b. Transport Preference: Limousine
    c. Number of Travelers: 1
    d. Mobility Requirements: none
    e. Departure Time: Now
    f. Origin: Current location (latitude, longitude)
    g. Destination: Desired location (latitude, longitude)
3. The Limousine Service receives the PMM from the Ride Request Database Service and coordinates with one of the limousines in its fleet.
4. An acknowledgement of the request is sent to the ride-requesting mobile device via cellular from the limo service.
5. The ride-requesting mobile device begins to exchange location information with the limo driver's mobile device via cellular that contains:
    a. location (Latitude, Longitude, Timestamp)
    b. Request ID
6. The limo driver's mobile device sends an acknowledgement message and begins to provide location information to the ride-requesting mobile device via cellular.
7. The limo approaches the ride-requesting user, who is waiting on the sidewalk for the vehicle.
8. The ride-requesting user boards the limo.
9. The ride-requesting mobile device exchanges coordination messages with the limo driver's mobile device.

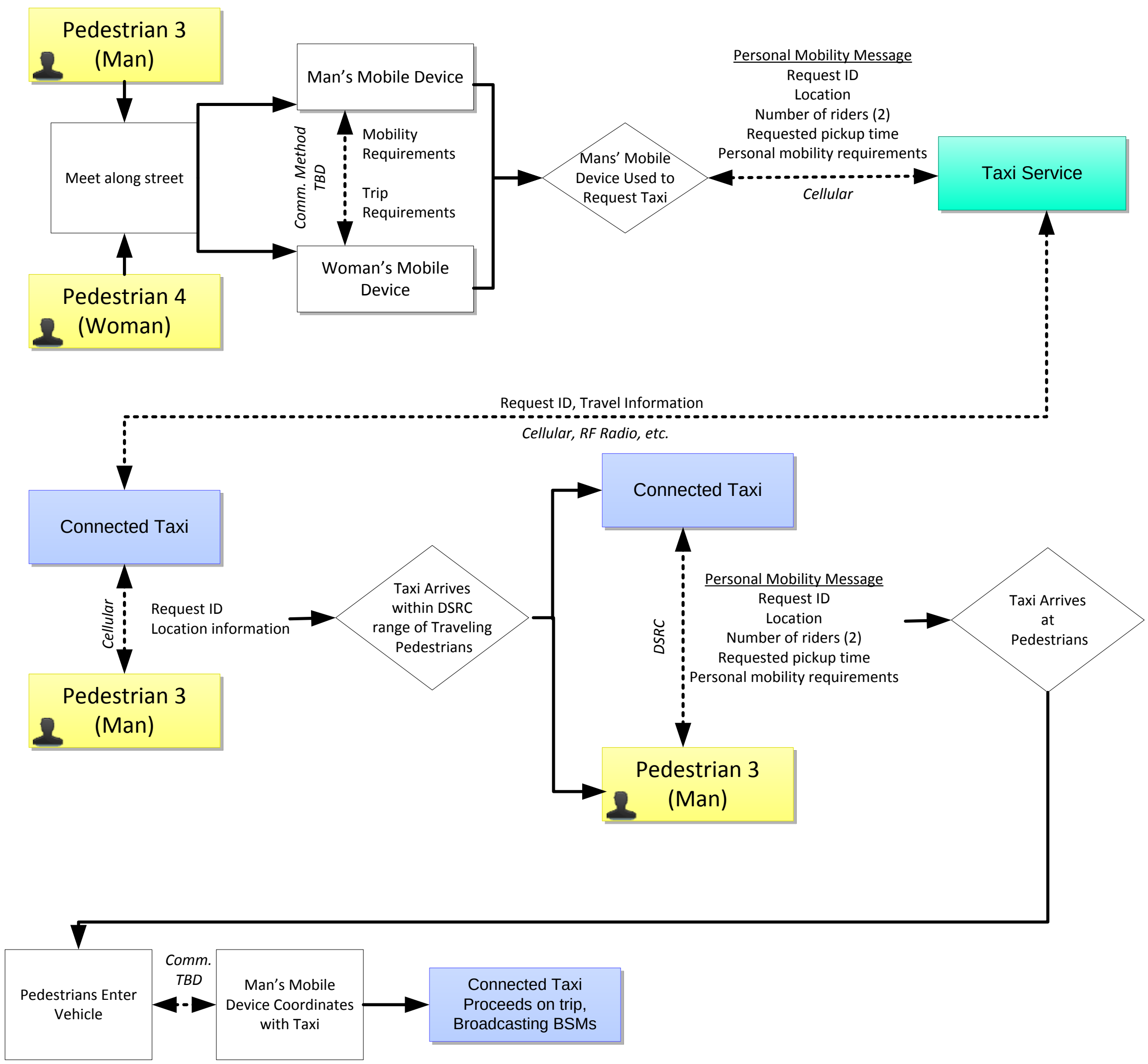
10. The ride-requesting mobile device determines that there are no other DSRC-equipped devices in the vehicle including the mobile device of the limo driver.
11. The ride-requesting mobile device begins to broadcast a Surrogate BSM, which is similar to a BSM but without the vehicle telematics elements to oncoming connected vehicles.
12. The limo proceeds on the trip.

Two Person Connected Taxi Trip

The following steps summarize the third component of Scenario 1, which is also illustrated in Figure 7-3.

1. A man and a woman pedestrian meet along the street and decide to share a taxi.
2. The man and woman decide that the man will use a connected vehicle application on his mobile device to indicate that they are seeking a taxi.
3. The man and woman's mobile devices coordinate, and the man's mobile device is set to the travel group leader function. The travel group leader function is responsible for coordinating travel for the group which entails exchanging mobility messages with transportation providers and managing the group with coordination messages. The travel group leader's mobile device does not send a PSM and only sends/receives coordination messages with the mobile device with the travel group leader function. Note: The specific communication method for this exchange of coordination messages between the two mobile devices will be wireless and could consist of a number of different protocols including Bluetooth, WiFi-Direct, etc. These will be selected following the requirements development as part of the system design process.
4. The application on his mobile device sends a Personal Mobility Message (PMM) to a Ride Request Database Service via cellular communications. This request includes:
    a. A request ID (randomly generated identifier):
    b. Transport Preference: Taxi
    c. Number of Travelers: 2
    d. Mobility Requirements: none
    e. Departure Time: Now
    f. Origin: Current location (latitude, longitude)
    g. Destination: Desired location (latitude, longitude)
5. A Taxi Provider receives the PMM from the Ride Request Database Service, and coordinates with a taxi in its fleet.
6. An acknowledgement of a taxi request is sent to the man's mobile device.
7. The man's mobile device begins to exchange location information with the taxi that contains:
    a. Their location (Latitude, Longitude, Timestamp)
    b. The Request ID
8. A connected taxi cab driving towards the pair receives the request for a pickup via cellular connectivity and exchanges its location with the man's mobile device.

9. The taxi proceeds towards the pair until it determines that it is within DSRC range. The taxi switches to DSRC messages at 1 second (or faster) intervals and broadcasts:
    a. BSM/Vehicle Probe
    b. Acknowledgement of the Request ID
10. The man's mobile device determines that the taxi is within DSRC range and switches to broadcasting PMMs at 10 second intervals (or faster intervals) with their location and Request ID.
11. As the taxi approaches the pair, the taxi continuously updates the driver and the man using PMM DSRC messages of their respective location.
12. The taxi driver safely identifies the pair traveling and pulls over to the side of the road.
13. The pair board the taxi.
14. The man and woman's mobile device exchanges coordination messages with the taxi driver's mobile device and the connected vehicle.
15. As a result of this coordination, the man's mobile devices cease to broadcast the PMM and PSM messages via DSRC.
16. The taxi, with the man and woman passengers continues on the trip broadcasting only BSM and Vehicle Probe Messages using the vehicle's DSRC equipment.
17. The taxi exchanges BSM and Vehicle Probe Messages with other connected vehicles.



Source: Battelle

Figure 7-3. Illustration of Flow of Events for the Third Sequence of Events in Scenario 1

Driver(s) of Personal Automotive Connected Vehicle(s)

1. Each driver of a POV (personally owned vehicle) starts their respective vehicle.
2. The vehicle and the driver's mobile device exchange coordination messages.
3. The driver's mobile device determines that the vehicle is equipped with DSRC technology and does not broadcast BSM or Vehicle Probe Messages (NOTE: if this is a vehicle that does not have DSRC technology, the driver's mobile device will identify that it needs to serve as a nomadic device and will initiate broadcasting of Surrogate BSMs, which are similar to a BSM and/or Probe messages but without the vehicle telematics component data).
4. The vehicle's DSRC radio receives and processes BSM/Vehicle Probe Messages and displays the appropriate message/indicator to the driver.
5. The vehicle transverses the road segment at random points during the scenario.

7.2 Small-Scale Scenario 2 – Large Number of Passengers Waiting for Two Transit Vehicles at a Transit Stop Near an Intersection with Some Travelers Boarding/Disembarking and Others Crossing the Intersection.

7.2.1 Small-Scale Scenario 2 – Prerequisites and Scenario Conditions

This scenario is based upon the real-world events associated with multiple groups of travelers clustering at a transit station/stop following a major event with multiple transit vehicles servicing the same station/stop. Specific interactions and events included in this scenario are:

1. Coordination of mobile devices and the Roadside Equipment (RSE) when a pedestrian wants to use a crosswalk.
2. PMM coordination of mobile devices between multiple pedestrians traveling together
3. Coordinated PMM exchange for requesting the transit bus (with specific mobility needs)
4. Multiple coordinated PMM exchanges (between a group and the transit system) confirming transit capacity needs for all of the groups
5. Coordinated PSM exchange for pedestrians in the street

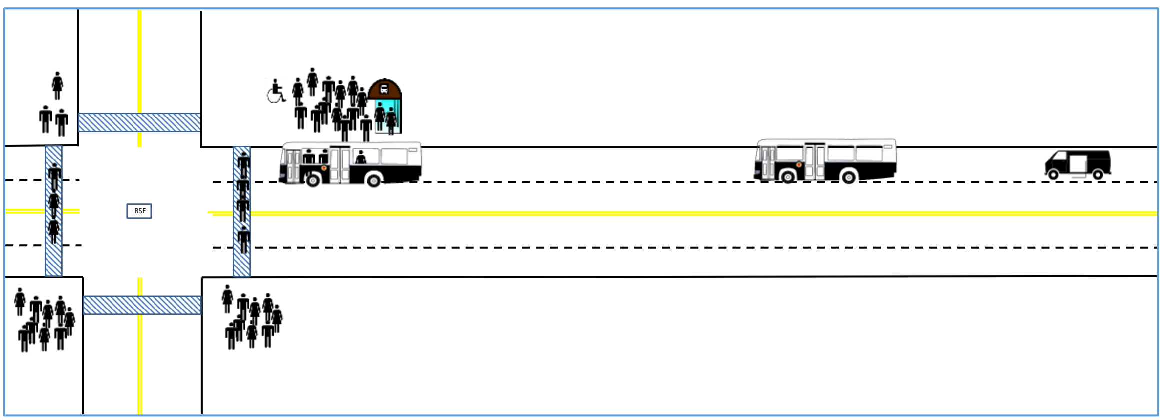
This scenario will be used to investigate the benefits of coordination of mobile devices in an environment where cellular, WiFi, and DSRC bandwidth are at a diminished service capacity because of the demands placed upon these communication protocols by large numbers of users. In this scenario, coordination of the mobile devices at the transit station being carried by the individual travelers and the Road Side Equipment (RSE) is expected to occur to reduce the amount of radio signal processing that needs to be performed by the transit vehicle connected technology.

The following summarizes the prerequisites and scenario conditions

- This scenario will be enacted at the Turner-Fairbank Highway Research Center (TFHRC)
- This scenario is envisioned to take place in an urban setting following the ending of a major event.
- Potential transit riders have begun to move towards predetermined transit locations in large numbers (3 groups of approximately 10 people).
- One group of pedestrians crosses the street in the crosswalk. All pedestrians are assumed to be in compliance with all traffic laws, signal crossings, etc.
- The scenario will be assumed to occur in good visibility, daylight hours.
- Each of the large transit vehicles has seating/standing room for 50 passengers (35 seats with an additional 15 passengers standing).
- The first transit vehicle already has 17 seats occupied by previous riders.

- All pedestrians and vehicles are assumed to have cellular, DSRC, Bluetooth, WiFi, NFC and other communications protocols typically found in mobile devices.
- The RSE has cellular, DSRC, Bluetooth, WiFi and other communications protocols available. DSRC coverage includes the entire intersection and the transit stop.
- The RSE broadcasts MAP and SPaT messages and is equipped with a Pedestrian in Signalized Crosswalk connected vehicle application.
- The transit stop is not a "connected stop" with a separate ITS component contained within it.
- Cellular coverage and GPS is available to all vehicles and travelers.
- All mobile devices and vehicle communications equipment is fully functional.

Figure 7-4 provides a high-level illustration of this scenario that encompasses these conditions and prerequisites. As illustrated in the figure, multiple travelers have gathered at all four corners of an intersection following the ending of a large event. In one corner of the intersection, there is a transit stop that is within range of the RSE positioned at the intersection. Three transit vehicles, two large shuttle transit vehicles and one paratransit vehicle, are servicing the transit stop. The first transit vehicle, which is partially full, has arrived at the transit stop while the empty second transit shuttle and the paratransit vehicle are still en-route. In addition to waiting for the transit vehicles, pedestrians are crossing the intersection within the crosswalks.

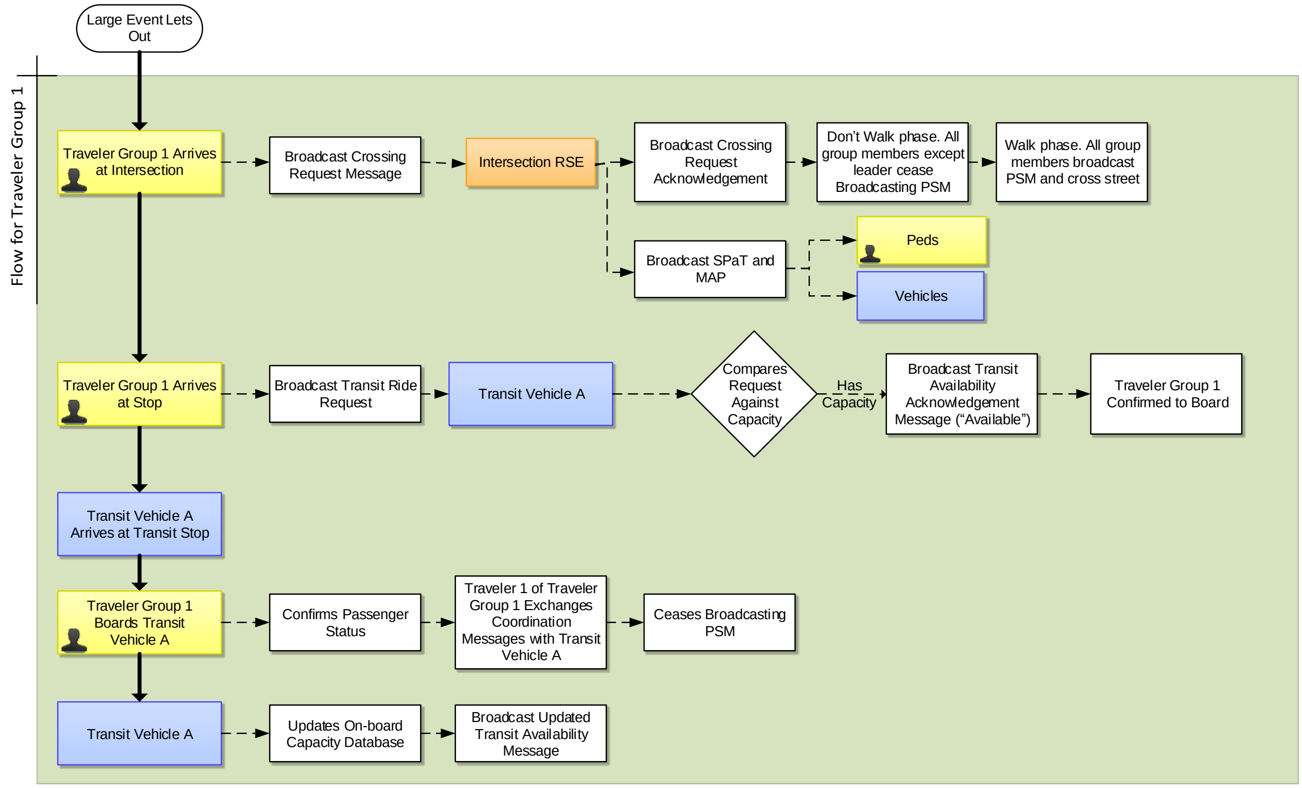


Source: Battelle

Figure 7-4. Graphical Representation of the Scenario Conditions for Small-Scale Scenario 2

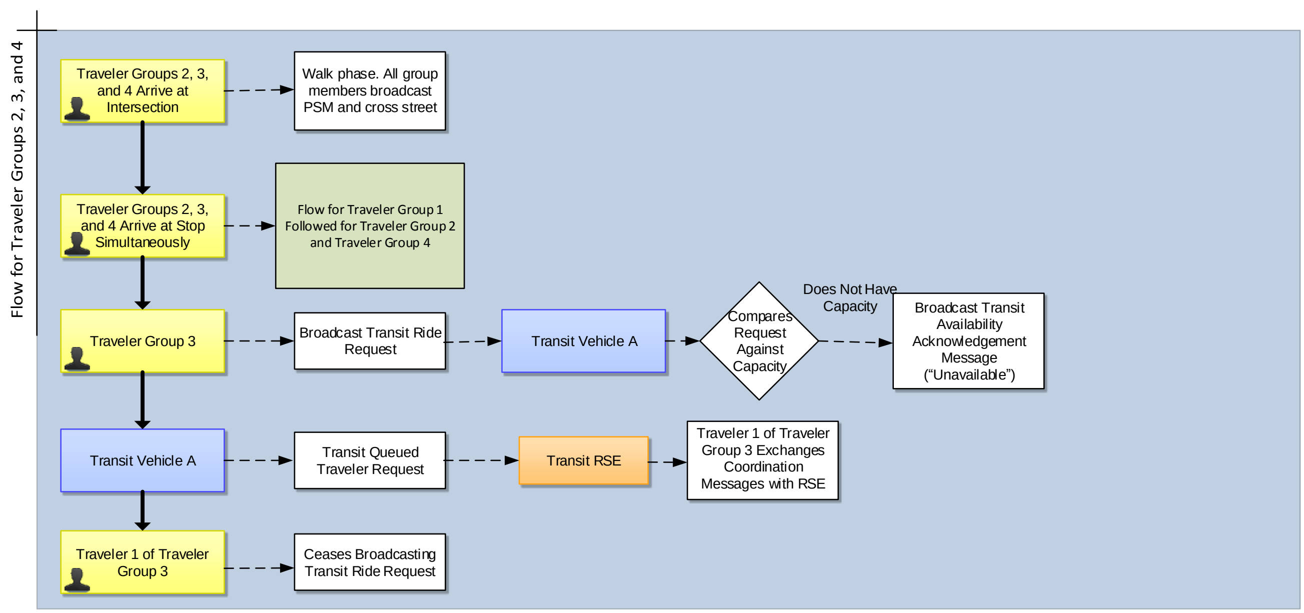
7.2.2 Small-Scale Scenario 2 – Description of Events/Process

This scenario is designed to represent a situation where there are large numbers of mobile devices transmitting PMMs and PSMs, which results in a reduction in bandwidth. The scenario then includes the coordination of mobile devices in the known groups to improve the bandwidth. This scenario is constrained to only include three vehicles, though in actuality additional connected and non-connected vehicles would represent a real-world scenario. Figure 7-5 through Figure 7-7are provided to assist the reader in understanding the sequence of events that are anticipated to occur in this scenario and to assist in following the events enumerated below in three segments of the scenario for readability and included in entirety (Figure 7-8) following the three figures to illustrate the overall flow of events.



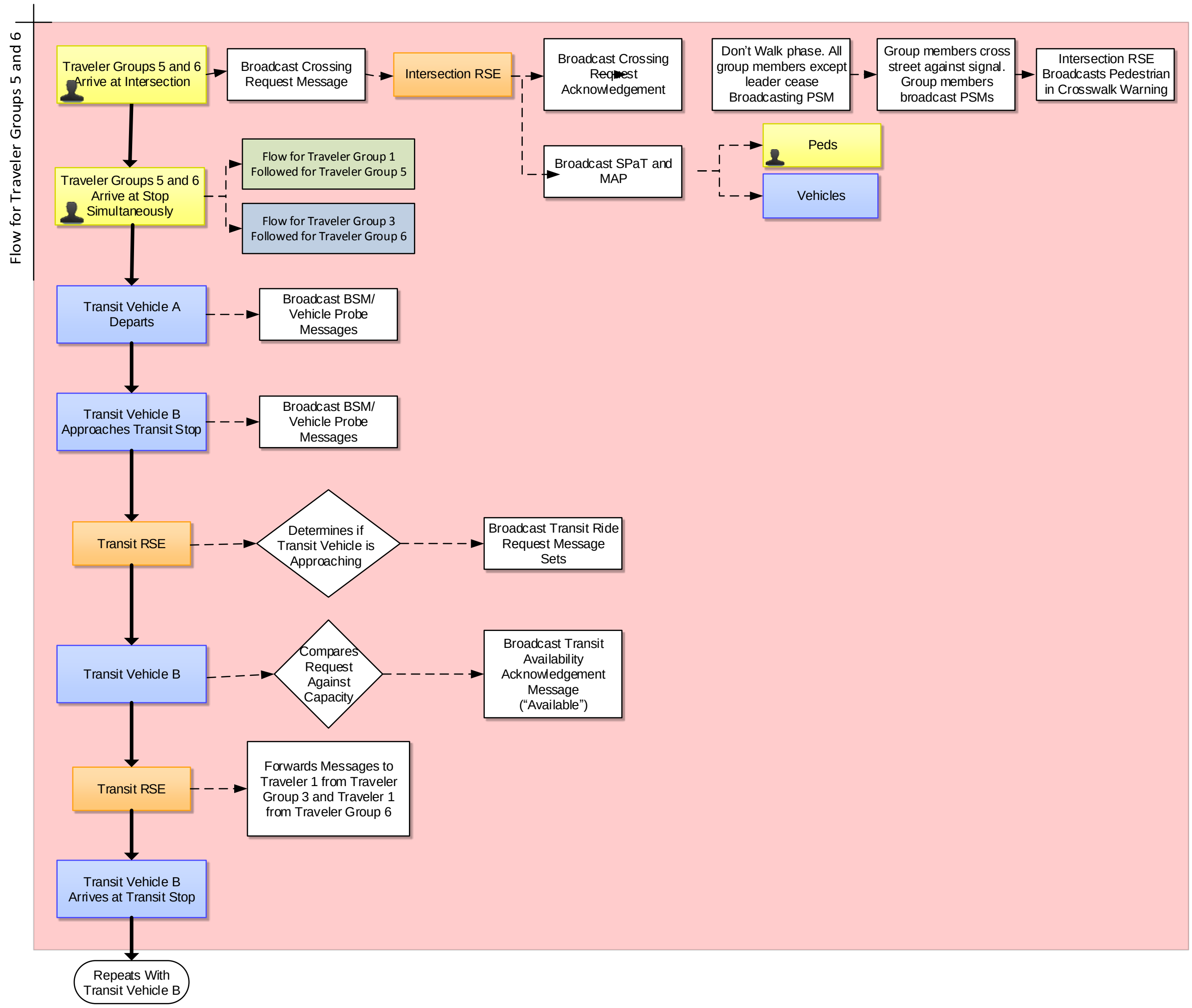
Source: Battelle

Figure 7-5. First Set of Events for Scenario 2



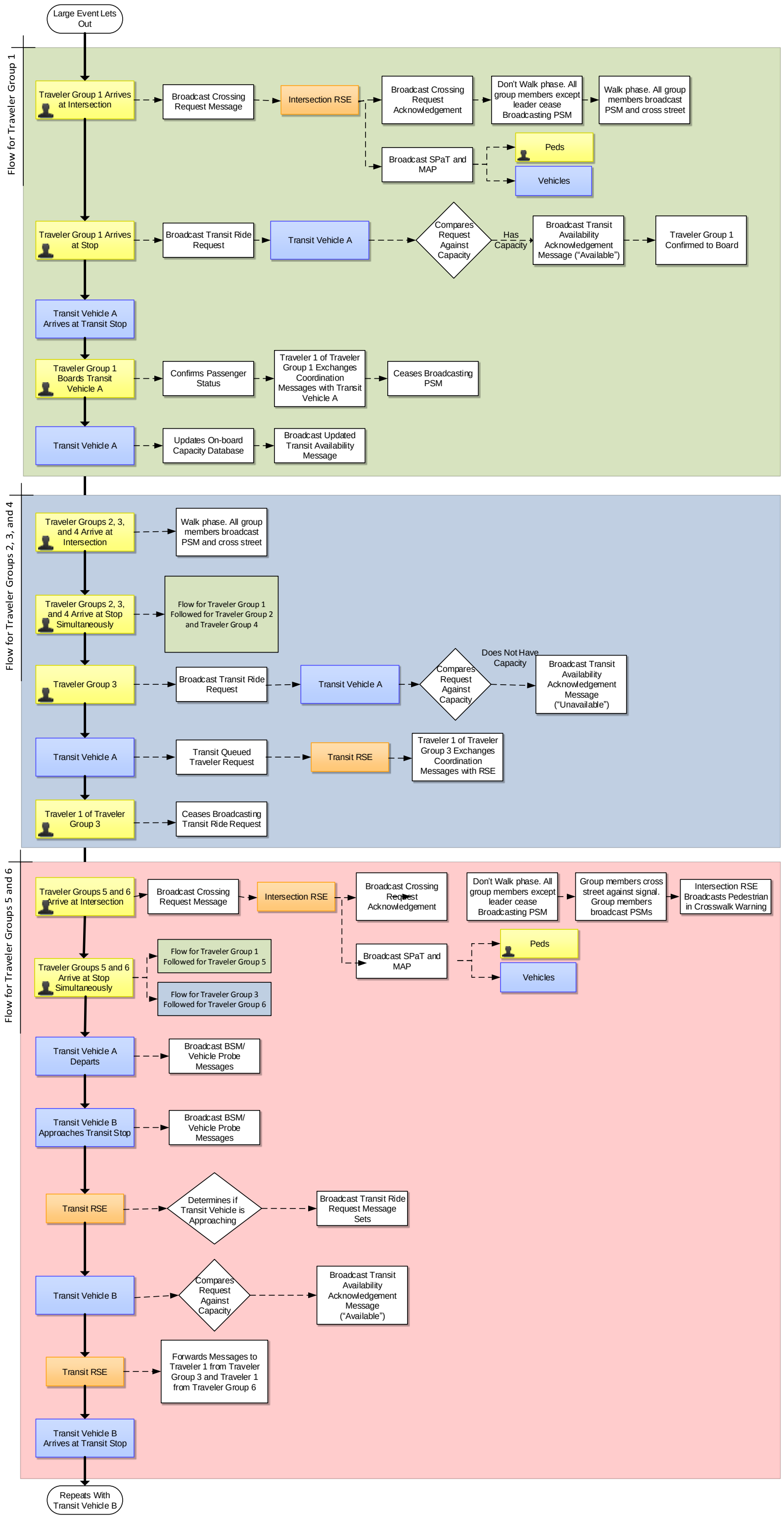
Source: Battelle

Figure 7-6. Second Set of Events for Scenario 2



Source: Battelle

Figure 7-7. Final Set of Events for Scenario 2



Source: Battelle

Figure 7-8. Sequence of Events for Small Scale Scenario 2

The following is a list of the events in this scenario enumerated sequentially:

1. Event lets out.
2. First group of five (5) travelers on the SE corner of an intersection must cross northbound on the East Crosswalk to access the transit stop.
3. Each traveler is broadcasting PSMs and is receiving SPaT and MAP messages from the intersection RSE via DSRC. The MAP message reveals the layout of the intersection while the SPaT message reveals the following conditions:
    a. Current Cycle Plan
        i. East and West (NB/SB) crosswalk timing plan
            1. Walk – 0 seconds
            2. Don't Walk Flashing – 15 seconds
            3. Don't Walk Solid – 27 seconds
        ii. North and South (EB/WB) crosswalk timing plan
            1. Walk – 30 seconds
            2. Don't Walk Flashing – 45 seconds
            3. Don't Walk Solid – 57 seconds
    b. Current Time in Cycle – 35 seconds
4. While at the SE corner, each pedestrian's mobile device understands that it is located on the SE corner of the intersection and that the pedestrian wants to use the East Crosswalk (northbound). Each pedestrian's mobile devices notifies each pedestrian that the East Crosswalk is in the "Don't Walk" phase.
5. The mobile devices of all travelers in the travel group recognize that there are others that want to use the Crosswalk, coordinate, and determine that Traveler 1 will be the group leader. The mobile device of Traveler 1 send a Crossing Request message to the Intersection RSE.
    a. Number of Persons Crossing Street – 5
    b. Minimum Pedestrian Crossing Speed – 1 meter per second
6. The Intersection RSE sends an acknowledgement of message back to the mobile device of Traveler 1 which in turn sends the acknowledgement to all members of the travel group. The Intersection RSE may adjust the pedestrian phase timing to accommodate the minimum pedestrian crossing speed.
7. All members of the travel group except Traveler 1 stop broadcasting PSMs.
8. When the East crosswalk phase changes to "Walk", each pedestrian's mobile device:
    a. Notifies the user that the East Crosswalk is in the "Walk" phase.
    b. Resumes broadcasting PSMs.
9. While the travelers are in the Eastbound crosswalk:
    a. The intersection RSE receives PSMs from the travelers' mobile devices to detect that the East Crosswalk is being used.
    b. The mobile devices use the MAP received from the intersection RSE to detect that they are in the East Crosswalk and change the status of their PSM to indicate that a street-crossing is in progress.

10. The pedestrians finish crossing the street and proceed to the transit stop. The intersection continues receiving PSMs from the travelers.

11. Transit Bus A arrives at stop.

- a. Sends message (cellular) to dispatch that it is at the stop
- b. Broadcasts Transit Availability Message via DSRC
  - i. Available capacity
    - 1. Regular seating – 17
    - 2. Handicap seating – 0
    - 3. Wheelchair access – 0
    - 4. Standing – 15
  - ii. Departure time
  - iii. Destination

12. First group of five (5) travelers (Traveler Group 1) arrives at the bus stop.

- a. The mobile devices of Traveler Group 1 coordinate with each other and determine that they are a group of travelers traveling together. Traveler 1 of Traveler Group 1 is the group leader.
- b. The mobile device of Traveler Group 1's group leader broadcasts a Personal Mobility Message (PMM) via DSRC. This request includes:
  - a. A request ID (randomly generated identifier):
  - b. Transport Preference: Transit Bus
  - c. Number of Travelers: 5
  - d. Mobility Requirements:
    - i. Regular seat (0)
    - ii. Handicap seat (0)
    - iii. Wheelchair access (0)
    - iv. Standing (0)
    - v. No Preference (5)
  - e. Departure Time: Now
  - f. Origin: Transit Stop A (latitude, longitude)
  - g. Destination: Transit Stop B (latitude, longitude)
- c. The Traveler Group 1's group leader manages the group through coordination messages, and the mobile devices of all members of the travel group, except that of the group leader, stop broadcasting PSMs.
- d. The Transit Stop RSE is able to send weather information, traveler information, Car/bike-sharing service information, etc. to the travelers via communications media available at the Transit Stop RSE at regular intervals (Note: Standardized message formats for these message types are currently not defined).

13. A Transit Provider receives the PMMs from the Ride Request Database Service, and coordinates with a Transit Vehicle in its fleet.

14. Transit Vehicle A receives the Transit Ride Request from Traveler 1.

15. Transit Vehicle A compares the Transit Ride Request from the mobile device of Traveler 1 of Traveler Group 1 against its on-board capacity database.

16. Transit Vehicle A returns a Transit Availability Acknowledgment message via DSRC to Traveler 1's mobile device.

   a. Availability – “Available”
   b. Regular seats (5)
   c. Handicap seat (0)
   d. Wheelchair access (0)
   e. Standing (0)

17. Traveler Group 1 boards Transit Vehicle A beginning with Traveler 1.

18. The mobile device of Traveler 1 coordinates with Transit Vehicle A and acknowledges that Traveler Group 1 are passengers on-board Transit Vehicle A.

19. All five travelers in Traveler Group 1 take seats and mobile device of Traveler 1 ceases broadcasting. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

   a. Regular seating – 12
   b. Handicap seating – 0
   c. Wheelchair access – 0
   d. Standing – 15

20. Transit Vehicle A broadcasts via DSRC an updated Transit Availability Message.

21. Next group of seventeen (17) travelers on the SE corner of an intersection must cross northbound on the East Crosswalk to access the transit stop.

22. Each traveler is broadcasting PSMs and are receiving SPaT and MAP messages from the intersection RSE via DSRC. The MAP message reveals the layout of the intersection and the SPaT message reveals the following conditions:

   a. Current Cycle Plan
      i. East and West (NB/SB) crosswalk timing plan
         1. Walk – 0 seconds
         2. Don’t Walk Flashing – 15 seconds
         3. Don’t Walk Solid – 27 seconds
      ii. North and South (EB/WB) crosswalk timing plan
         1. Walk – 30 seconds
         2. Don’t Walk Flashing – 45 seconds
         3. Don’t Walk Solid – 57 seconds

   b. Current Time in Cycle – 2 seconds

23. While at the SE corner, each pedestrian’s mobile device understands that it is located on the SE corner of the intersection and that the pedestrian wants to use the East Crosswalk (northbound). Each pedestrian’s mobile devices notifies each pedestrian that the East Crosswalk is in the “Walk” phase.

24. The mobile devices of all travelers do not coordinate. Each traveler’s mobile device determines that each traveler can complete the street crossing before the pedestrian phase ends, and the travelers cross the street.

25. While the travelers are in the East Crosswalk
   a. The intersection RSE receives PSMs from the travelers’ mobile devices to detect that the East Crosswalk is being used.

   b. The mobile devices use the MAP received from the intersection RSE to detect that they are in the East Crosswalk and change the status of their PSM to indicate that a street-crossing is in progress.

26. The pedestrians finish crossing the street and proceed to the transit stop. The intersection continues receiving PSMs from the travelers.

27. The second, third, and fourth groups of travelers (Traveler Group 2, Traveler Group 3, and Traveler Group 4) are formed at the bus stop and are comprised of the seventeen (17) members that recently finished using the crosswalk.

a. Traveler Group 2 is a large group of 10 travelers.
b. Traveler Group 3 is a small group of 3 travelers, with Traveler 1 requiring wheelchair accessible transport.
c. Traveler Group 4 is a large group and has 4 travelers whom require seating.
d. The Transit Stop RSE is able to send weather information, traveler information, Car/bike-sharing service information, etc. to the travelers via communications media available to the Transit Stop RSE at regular intervals (Note: Standardized message formats for these message types are currently not defined).

28. The mobile devices of each Traveler Group coordinate with each other to determine that they are a group of travelers traveling together.

29. Each group leader manages their group through coordination messages, and all members of each travel group, except the group leader, stop broadcasting PSMs.

30. The mobile device of Traveler Group 2's group leader broadcasts a Personal Mobility Message (PMM) via DSRC. This request includes:

a. A request ID (randomly generated identifier):
b. Transport Preference: Transit Bus
c. Number of Travelers: 10
d. Mobility Requirements:
   i. Regular seat (0)
   ii. Handicap seat (0)
   iii. Wheelchair access (0)
   iv. Standing (0)
   v. No preference (10)
e. Departure Time: Now
f. Origin: Transit Stop A (latitude, longitude)
g. Destination: Transit Stop B (latitude, longitude)

31. The mobile device of Traveler Group 3's group leader broadcasts a Personal Mobility Message (PMM) via DSRC. This request includes:

a. A request ID (randomly generated identifier):
b. Transport Preference: Transit Bus
c. Number of Travelers: 3
d. Mobility Requirements:
   i. Regular seat (0)
   ii. Handicap seat (0)
   iii. Wheelchair access (1)
   iv. Standing (0)
   v. No preference (2)

   e. Departure Time: Now
   f. Origin: Transit Stop A (latitude, longitude)
   g. Destination: Transit Stop C (latitude, longitude)

32. The mobile device of Traveler Group 4's group leader broadcasts a Personal Mobility Message (PMM) via DSRC. This request includes:

   a. A request ID (randomly generated identifier):
   b. Transport Preference: Transit Bus
   c. Number of Travelers: 8
   d. Mobility Requirements:
      i. Regular seat (4)
      ii. Handicap seat (0)
      iii. Wheelchair access (0)
      iv. Standing (0)
      v. No preference (4)
   e. Departure Time: Now
   f. Origin: Transit Stop A (latitude, longitude)
   g. Destination: Transit Stop D (latitude, longitude)

33. A Transit Provider receives the PMMs from the Ride Request Database Service and coordinates with a Transit Vehicle in its fleet.

34. Transit Vehicle A simultaneously receives the Transit Ride Request from:

   a. Traveler 1 of Traveler Group 2
   b. Traveler 1 of Traveler Group 3
   c. Traveler 1 of Traveler Group 4

35. Transit Vehicle A compares the Transit Ride Request from these three mobile devices against its on-board capacity database.

   a. Transit Vehicle A determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.

36. Transit Vehicle A broadcasts the following Transit Availability Acknowledgment messages to Traveler 1 of Traveler Group 2 and Traveler Group 4:

   a. Traveler 1 of Traveler Group 2:
      i. Availability – "Available"
      ii. Regular seats (8)
      iii. Handicap seat (0)
      iv. Wheelchair access (0)
      v. Standing (2)
   b. Traveler 1 of Traveler Group 4:
      i. Availability – "Available"
      ii. Regular seats (4)
      iii. Handicap seat (0)
      iv. Wheelchair access (0)
      v. Standing (4)

37. Transit Vehicle A broadcasts (DSRC) Transit Availability Acknowledgment Message to Traveler 1 of Traveler Group 3:

a. Availability – “Not enough capacity for your group. Reserved Position 1 on Next Transit Vehicle”
b. Queue Position ID: 1
c. Regular seats (0)
d. Handicap seat (0)
e. Wheelchair access (1)
f. Standing (0)
g. No Preference (2)

38. Transit Vehicle A sends a Transit Queued Traveler Request to the RSE (DSRC) at the intersection that includes the Queue Position ID and requested seats:

a. Availability – “Not enough capacity for your group. Reserved Position 1 on Next Transit Vehicle”
b. Queue Position ID: 1
c. Number of Travelers (3)
d. Regular seats (0)
e. Handicap seat (0)
f. Wheelchair access (1)
g. Standing (0)
h. No preference (2)

39. The mobile device of Traveler 1 of Traveler Group 3 coordinates with the RSE and ceases to broadcast a Personal Mobility Message – Transit Ride Request

40. Travelers in Traveler Group 2 board Transit Vehicle A

41. The mobile device of Traveler 1 of Traveler Group 2 coordinates with Transit Vehicle A and acknowledges Traveler Group 2 are passengers on-board Transit Vehicle A.

42. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

a. Regular seating – 4
b. Handicap seating – 0
c. Wheelchair access– 0
d. Standing – 13

43. Travelers in Traveler Group 4 board Transit Vehicle A

44. The mobile device of Traveler 1 of Traveler Group 4 coordinates with Transit Vehicle A and acknowledges Traveler Group 4 are passengers on-board Transit Vehicle A.

45. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

a. Regular seating – 0
b. Handicap seating – 0
c. Wheelchair access – 0
d. Standing – 9

46. Transit Vehicle A broadcasts an updated Transit Availability Message (DSRC).

47. Next group of thirteen (13) travelers on the SE corner of an intersection must cross northbound on the East Crosswalk to access the transit stop.

48. Each traveler is broadcasting PSMs, and are receiving SPaT and MAP messages from the intersection RSE via DSRC. The MAP message reveals the layout of the intersection while the SPaT message reveals the following conditions:

   a. Current Cycle Plan
      iii. East and West (NB/SB) crosswalk timing plan
         4. Walk – 0 seconds
         5. Don't Walk Flashing – 15 seconds
         6. Don't Walk Solid – 27 seconds
      iv. North and South (EB/WB) crosswalk timing plan
         7. Walk – 30 seconds
         8. Don't Walk Flashing – 45 seconds
         9. Don't Walk Solid – 57 seconds

   b. Current Time in Cycle – 50 seconds

49. While at the SE corner, each pedestrian's mobile device understands that it is located on the SE corner of the intersection and that the pedestrian wants to use the East Crosswalk (northbound). Each pedestrian's mobile devices notifies each pedestrian that the East Crosswalk is in the "Don't Walk" phase.

50. The mobile devices of all travelers in the travel group recognize that there are others that want to use the Crosswalk, coordinate, and determine that Traveler 1 will be the group leader. The mobile device of Traveler 1 sends a Crossing Request message to the Intersection RSE.

   a. Number of pedestrians waiting - 13
   b. Minimum Pedestrian Crossing Speed – 1.5 meters per second

51. The Intersection RSE sends an acknowledgement of message back to the mobile device of Traveler 1 which in turn, sends the acknowledgement to all members of the travel group. The intersection RSE may adjust the pedestrian phase timing to accommodate the minimum pedestrian crossing speed.

52. All members of the travel group except Traveler 1 stop broadcasting PSMs.

53. There is no visible cross-traffic, and the group decides to cross against the signal indication. As each pedestrian enters the crosswalk, their respective mobile device resumes broadcasting PSMs.

54. A warning is issued to each pedestrian's mobile device as they enter the crosswalk against the signal indication.

55. While the travelers are in the East Crosswalk

   a. The intersection RSE receives PSMs from the travelers' mobile devices to detect that the East Crosswalk is being used.

   b. The mobile devices use the MAP received from the intersection RSE to detect that they are in the East Crosswalk and change the status of their PSM to indicate that a street-crossing is in progress.

56. Vehicles that approach the intersection from the east or the west intersection approaches would interpret the East Crosswalk Status along with the receipt of

PSMs from pedestrians in the crosswalk to determine that a Pedestrian in Crosswalk warning needs to be issued to the vehicle driver.

57. The pedestrians finish crossing the street and proceed to the transit stop.

58. Traveler Group 5 and Traveler Group 6 arrive simultaneously at the transit stop.

a. Traveler Group 5 has 7 travelers.
b. Traveler Group 6 has 6 travelers
c. The Transit Stop RSE is able to send weather information, traveler information, Car/bike-sharing service information, etc. to the travelers via communications media available to the Transit Stop RSE at regular intervals (Note: Standardized message formats for these message types are currently not defined).

59. The mobile devices of each Traveler Group coordinate with each other and determine that they are a group of travelers traveling together.

60. Each group leader manages their group through coordination messages, and all members of each travel group except the group leader stop broadcasting PSMs.

61. The mobile device of Traveler Group 5's group leader broadcasts a Personal Mobility Message (PMM) via DSRC. This request includes:

a. A request ID (randomly generated identifier):
b. Transport Preference: Transit Bus
c. Number of Travelers: 7
d. Mobility Requirements:

    i. Regular seat (0)
    ii. Handicap seat (0)
    iii. Wheelchair access (0)
    iv. Standing (0)
    v. No preference (7)

e. Departure Time: Now
f. Origin: Transit Stop A (latitude, longitude)
g. Destination: Transit Stop B (latitude, longitude)

62. The mobile device of Traveler Group 6's group leader broadcasts a Personal Mobility Message (PMM) via DSRC. This request includes:

a. A request ID (randomly generated identifier):
b. Transport Preference: Transit Bus
c. Number of Travelers: 6
d. Mobility Requirements:

    i. Regular seat (0)
    ii. Handicap seat (0)
    iii. Wheelchair access (0)
    iv. Standing (0)
    v. No preference (6)

e. Departure Time: Now
f. Origin: Transit Stop A (latitude, longitude)
g. Destination: Transit Stop D (latitude, longitude)

63. A Transit Provider receives the PMMs from the Ride Request Database Service and coordinates with a Transit Vehicle in its fleet.

64. Transit Vehicle A compares the Transit Ride Request from these three mobile devices against its on-board capacity database.

   a. Transit Vehicle A determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.

65. Transit Vehicle A broadcasts (DSRC) the following Transit Availability Acknowledgment message to Traveler 1 of Traveler Group 5:

   a. Availability – “Available”
   b. Regular seats (8)
   c. Handicap seat (0)
   d. Wheelchair access (0)
   e. Standing (2)

66. Transit Vehicle A broadcasts (DSRC) Transit Availability Acknowledgment messages to the Traveler 1 of Traveler Group 6:

   a. Availability – “Not enough capacity for your group. Reserved Position 2 on Next Transit Vehicle”
   b. Queue Position ID: 2
   c. Regular seats (0)
   d. Handicap seat (0)
   e. Wheelchair access (0)
   f. Standing (0)
   g. No Preference (6)

67. Transit Vehicle A sends a Transit Queued Traveler Request to the RSE (DSRC) at the intersection that includes the Queue Position ID and requested seats:

   a. Availability – “Not enough capacity for your group. Reserved Position 2 on Next Transit Vehicle”
   b. Queue Position ID: 2
   c. Number of Travelers (6)
   d. Regular seats ()
   e. Handicap seat (0)
   f. Wheelchair access (0)
   g. Standing (0)
   h. No preference (6)

68. The mobile device of Traveler 1 of Traveler Group 6 coordinates with the RSE and ceases to broadcast a Personal Mobility Message – Transit Ride Request.

69. Travelers in Traveler Group 5 board Transit Vehicle A.

70. The mobile device of Traveler 1 of Traveler Group 5 coordinates with Transit Vehicle A and acknowledges that Traveler Group 5 are passengers on-board Transit Vehicle A.

71. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

   a. Regular seating – 0
   b. Handicap seating – 0

    c. Wheelchair access – 0
    d. Standing – 2

72. Transit Vehicle A determines that it has exceeded 90% capacity and alerts the transit operator to cease boarding and depart the transit stop.

73. Transit Vehicle A departs the bus stop.

74. Transit Vehicle A communicates with transit dispatch (cellular) to indicate that it is en-route to its next destination.

75. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

    a. Seating – 0
    b. Handicap seating – 0
    c. Wheelchair access – 0
    d. Standing – 2

76. Transit Vehicle B approaches the transit stop while broadcasting BSM/Vehicle Probe messages (DSRC).

77. Transit Vehicle B begins to broadcast a Transit Capacity Message (DSRC).

    a. Available capacity
        i. Regular seating – 31
        ii. Handicap seating – 2
        iii. Wheelchair access -- 2
        iv. Standing -- 10
    b. Departure time
    c. Origin:
    d. Destination:

78. The RSE at the intersection identifies that Transit Vehicle B is approaching and issues a Transit Ride Request Message Set (DSRC) to Transit Vehicle B containing two messages:

    a. Message Set 1
        a. A request ID (randomly generated identifier):
        b. Transport Preference: Transit Vehicle
        c. Number of Travelers: 1
        d. Mobility Requirements:
            i. Regular seat (0)
            ii. Handicap seat (0)
            iii. Wheelchair access (1)
            iv. Standing (0)
            v. No preference (2)
        e. Departure Time: Now
        f. Origin: Transit Stop A (latitude, longitude)
        g. Destination: Transit Stop C (latitude, longitude)
    b. Message Set 2
        a. A request ID (randomly generated identifier):
        b. Transport Preference: Transit Vehicle

   c. Number of Travelers: 6
   d. Mobility Requirements:
      i. Regular seat (0)
      ii. Handicap seat (0)
      iii. Wheelchair access (0)
      iv. Standing (0)
      v. No preference (6)
   e. Departure Time: Now
   f. Origin: Transit Stop A (latitude, longitude)
   g. Destination: Transit Stop D (latitude, longitude)

79. A Transit Provider receives the PMMs from the Ride Request Database Service and coordinates with a Transit Vehicle in its fleet.

80. Transit Vehicle B compares the Transit Ride Request from the RSE against its on-board capacity database.

   a. Transit Vehicle B determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.

81. Transit Vehicle B broadcasts the following Transit Availability Acknowledgment Message Sets (DSRC) to the RSE:

   a. Message Set 1:
      i. Availability – "Available"
      ii. Regular seats (2)
      iii. Handicap seat (0)
      iv. Wheelchair access (1)
      v. Standing (0)
   b. Message Set 2:
      i. Availability – "Available"
      ii. Regular seats (6)
      iii. Handicap seat (0)
      iv. Wheelchair access (0)
      v. Standing (0)

82. The RSE forwards the messages to Traveler 1 in Traveler Group 3 and Group 6.Transit Vehicle B begins to broadcast an updated Transit Capacity Message (DSRC).

   a. Available capacity
      i. Regular seating – 23
      ii. Handicap seating – 2
      iii. Wheelchair access – 1
      i. Standing – 10
   b. Departure time
   c. Destination

83. Transit Vehicle B arrives at the Transit Stop.

84. Steps 1-82 repeat with additional traveler groups and transit vehicles.

7.3 Small-Scale Scenario 3 – Multiple-Transit Vehicles, Multiple Travelers with Different Mobility Needs, with Multiple Transit Stops

7.3.1 Small-Scale Scenario 3 – Objective, Summary, and Relation to Real-World Event

The objective of the third scenario for the small-scale demonstration is to examine the impact of coordinated versus uncoordinated messages in a multi-vehicle, multi-stop sequence taking into account the mobility needs of each traveler. This scenario simulates a typical transit vehicle picking up/dropping off passengers at multiple transit stops while interacting with other vehicles who may or may not be picking up or dropping off passengers at the same stops. Specific interactions and events included in this scenario are:

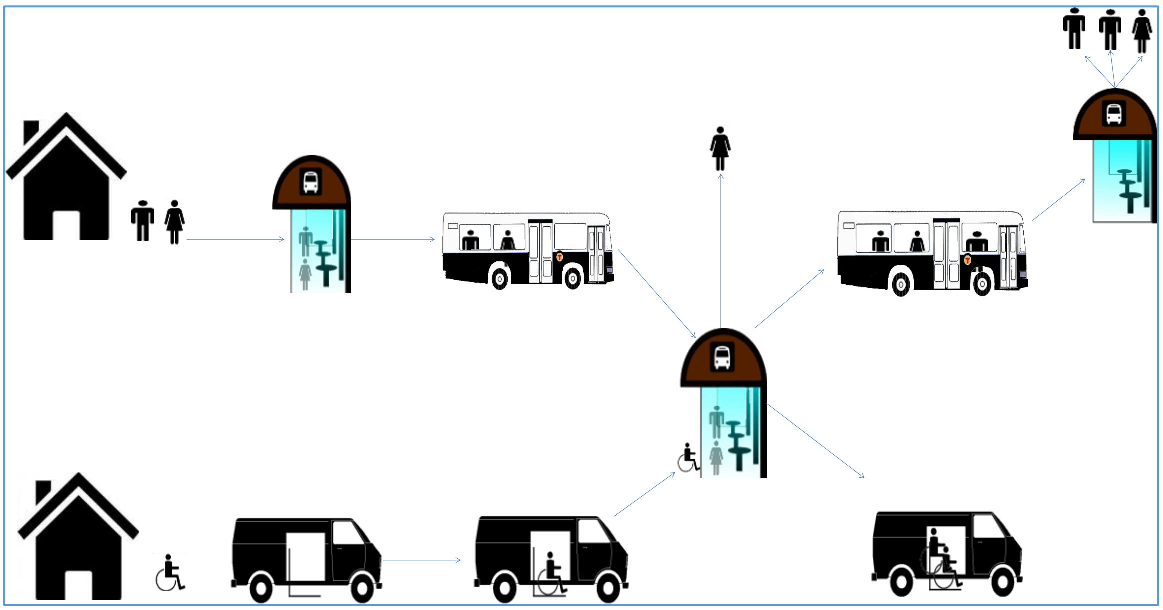
1. Coordinating a trip from home before going to the transit pickup location
2. Canceling a trip
3. PMM coordination of mobile devices between two pedestrians
4. Coordinated PMM exchange for transit request and pickup
5. PMM coordination between passengers and a connected vehicle
6. PMM to cease coordination of passengers and a connected vehicle

7.3.2 Small-Scale Scenario 3 – Prerequisites and Scenario Conditions

The following summarizes the prerequisites and scenario conditions

- This scenario will be enacted at the Turner-Fairbank Highway Research Center (TFHRC)
- This scenario is envisioned to take place in a suburban setting along a city street.
- Each of the two transit vehicles has to stop at multiple stops to receive and deliver passengers.
- Travelers arranging for pick-up and drop-off will do so prior to the scenario (not a trip planning demonstration).
- The scenario will be assumed to occur in good visibility, daylight hours as well as in good visibility.
- Each vehicle will pick up passengers, but will not reach or exceed seating capacity.
- This scenario assumes that travelers have mobile devices that are capable of communicating through a number of different technologies including WiFi, Bluetooth, cellular, and DSRC.
- The vehicles are connected vehicles that are equipped with DSRC technology.
- Cellular coverage and GPS is available to all vehicles and travelers.
- All mobile devices and vehicle communications equipment is fully functional.

Figure 7-9 provides a high-level illustration of this scenario that encompasses these conditions and prerequisites. As illustrated in the figure, the scenario begins with a traveler(s) leaving their residence and either proceeding as a pedestrian to a transit stop or being picked-up by a vehicle at their residence. Travelers at the transit stop wait for the transit vehicle and interact with the transit stop to notify the transit vehicle that they are waiting for arrival. They board the transit vehicle and proceed to other stops with passengers boarding and disembarking at each stop. Along the transit route, the transit vehicle and the vehicle(s) with other travelers pass and communicate using connected vehicle technology. At one transit stop, the transit vehicle and another vehicle(s) arrive simultaneously and each pick-up a portion of the travelers at that stop before proceeding along their remaining route. Some passengers also disembark one of the transit vehicles as well. Variations to this scenario include the number of passengers boarding/disembarking the transit vehicle at each location, the number of transit stops, the number of transit and non-transit vehicles interacting at each stop, and the nature and characteristics of the travelers with respect to their travel needs and requirements.



Source: Battelle

Figure 7-9. Conceptualization of Small-Scale Scenario 3 – Multiple Transit Stops and Vehicles

7.3.3 Small-Scale Scenario 3 – Description of Events/Process

This scenario begins when three travelers depart from two residences. A sequential description of the events and processes that follow is listed below:

1. Traveler Group 1 consists of Traveler 1 and Traveler 2, who are both at home. The mobile devices of Traveler 1 and Traveler 2 coordinate and determine that Traveler 1 will be the group leader.
2. The mobile device of Traveler Group 1's group leader sends a Personal Mobility Message (PMM) to a Ride Request Database Service via cellular communications. Note: This could also be accomplished via WiFi, if the home of Traveler Group 1 is equipped with internet and a wireless router. This request includes:
    a. A request ID (randomly generated identifier):
    b. Transport Preference: Transit Bus

c. Number of Travelers: 2
d. Mobility Requirements:
  i. Regular Seat (2)
  ii. Handicap seat (0)
  iii. Wheelchair Access (0)
  iv. Standing (0)
  v. No Preference (0)
e. Departure Time: In 10 minutes (time it will take Traveler 1 and Traveler 2 to travel between home and the origin Transit Stop)
f. Origin: Transit Stop A (latitude, longitude)
g. Destination: Transit Stop B (latitude, longitude)

3. A Transit Provider receives the PMMs from the Ride Request Database Service and coordinates with a Transit Vehicle in its fleet.
4. Transit Vehicle A receives the relayed PMM and checks against its on-board capacity database.
   a. Transit Vehicle A determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.
5. Transit Vehicle A broadcasts the following Transit Availability Acknowledgment Message Sets (Cellular) to the Transit Dispatch Center:
   a. Message Set 1:
      a. Vehicle: Transit Vehicle A
      i. Availability – “Available”
      ii. Regular seats (2)
      iii. Handicap seat (0)
      iv. Wheelchair access (0)
      v. Standing (0)
6. The Transit Dispatch Center relays the Transit Availability Acknowledgement from Transit Vehicle A to Traveler Group 1. The message indicates that their ride request has been received and that there is availability on Transit Bus A.
7. Traveler Group 1 leaves their residence and begin to walk to Transit Stop A. Both devices are broadcasting Personal Safety Messages (PSM).
8. While en-route to Transit Stop A, Traveler 2 of Traveler Group 1 decides to return home and cancels their transit request.
9. Traveler 2’s mobile device sends a message to the group leader (Traveler 1) to indicate he/she is leaving the group. Note: if the group leader (Traveler 1) were to cancel his/her transit request, the group leader responsibility would be transferred to another member of the group (Traveler 2).
10. The Group Leader (Traveler 1) sends an updated PMM to the Ride Request Database Service via cellular communications.
    a. A request ID (same as previously generated identifier)
    b. Transport Preference: Transit Bus
    c. Number of Travelers: 1
    d. Mobility Requirements:
       i. Regular Seat (1)
       ii. Handicap seat (0)

        iii. Wheelchair Access (0)
        iv. Standing (0)
        v. No Preference (0)
    e. Departure Time: In 5 minutes (time it will take Traveler 1 to arrive at origin Transit Stop)
    f. Origin: Transit Stop A (latitude, longitude)
    g. Destination: Transit Stop B (latitude, longitude)

11. The Transit Provider receives the PMMs from the Ride Request Database Service, and re-coordinates with a Transit Vehicle in its fleet. Transit Vehicle A broadcasts the following Transit Availability Acknowledgment Message Sets (Cellular) to the Transit Dispatch Center

    b. Message Set 1:
        a. Vehicle: Transit Vehicle A
        vi. Availability – “Available”
        vii. Regular seats (1)
        viii. Handicap seat (0)
        ix. Wheelchair access (0)
        x. Standing (0)

12. The Transit Dispatch Center relays the Transit Availability Acknowledgement from Transit Vehicle A to Traveler Group 1. The message indicates that their ride request has been received and that there is availability on Transit Bus A.

13. Traveler 1 arrives at Transit Stop A. The Transit Stop RSE is able to send weather information, traveler information, Car/bike-sharing service information, etc. to the travelers via communications media available to the Transit Stop RSE at regular intervals (Note: Standardized message formats for these message types are currently not defined).

14. Transit Stop A broadcasts a PSM that alerts other vehicles that there are transit riders waiting at the transit stop via DSRC messages. The mobile devices of Traveler Group A stop sending PSMs.

15. Transit Vehicle A arrives at the Transit Stop A.

16. Traveler 1 boards Transit Vehicle A, and the mobile device of Traveler 1 coordinates with Transit Vehicle A and acknowledges that Traveler 1 is a passenger on-board Transit Vehicle A.

17. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

    a. Regular seating – 5
    b. Handicap seating – 0
    c. Wheelchair access – 0
    d. Standing – 13

18. Transit Vehicle A departs Transit Stop A and heads towards Transit Stop B while broadcasting BSM and Vehicle Probe messages.

19. Traveler Group 2 consisting of one wheelchair bound traveler (Traveler 3) who departs his residence and waits on the sidewalk for a paratransit vehicle.

20. The mobile device of Traveler Group 2's group leader sends a Personal Mobility Message (PMM) to a Ride Request Database Service via cellular communications. This request includes:

a. A request ID (randomly generated identifier):
b. Transport Preference: Transit Vehicle
c. Number of Travelers: 1
d. Mobility Requirements:
    i. Regular Seat (0)
    ii. Handicap seat (0)
    iii. Wheelchair Access (1)
    iv. Standing (0)
    v. No Preference (0)
e. Departure Time: Now
f. Origin: Traveler 3's Residence (latitude, longitude)
g. Destination: Transit Stop C (latitude, longitude)

21. A Transit Provider receives the PMMs from the Ride Request Database Service, and coordinates with a Transit Vehicle in its fleet.

22. Transit Vehicle B receives the relayed PMM and checks against its on-board capacity database.

b. Transit Vehicle B determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.

23. Transit Vehicle B sends the following Transit Availability Acknowledgment Message Sets (Cellular) to the Transit Dispatch Center:

c. Message Set 1:
    i. Vehicle: Transit Vehicle B
    ii. Availability – "Available"
    iii. Regular seats (0)
    iv. Handicap seat (0)
    v. Wheelchair access (1)
    vi. Standing (0)

24. The Transit Dispatch Center relays the Transit Availability Acknowledgement from Transit Vehicle B to Traveler 3. The message indicates that their ride request has been received and that there is availability on Transit Bus A.

25. Transit Vehicle B approaches the residence of Traveler 3 while broadcasting BSM and Vehicle Probe Messages as well as providing location updates to Traveler 3 via cellular communication at 60 second intervals.

26. Transit Vehicle B arrives at the residence of Traveler 3, who boards Transit Vehicle B.

27. Traveler 3's mobile device coordinates with Transit Vehicle B and acknowledges that Traveler 3 is a passenger in Transit Vehicle B.

28. Traveler 3's mobile device ceases to broadcast PSM and PMM.

29. Transit Vehicle B updates its on-board capacity database to indicate the current available capacity:

   a. Regular seating – 2
   b. Handicap seating – 0
   c. Wheelchair access – 1
   d. Standing – 0

30. Transit Vehicle B departs the residence of Traveler 3 and heads towards Transit Stop B.

31. Transit Vehicle A passes Transit Vehicle B en-route to Transit Stop B.

   a. BSM and Vehicle Probe Messages are exchanged.

32. Traveler 4, 5, and 6 are waiting at Transit Stop B, which is equipped with a Transit Stop RSE. The Transit Stop RSE is able to send weather information, traveler information, Car/bike-sharing service information, etc. to the travelers via communications media available at the Transit Stop RSE at regular intervals (Note: Standardized message formats for these message types are currently not defined).

33. The mobile devices of Traveler 4, 5, and 6 do not have cellular communication capabilities (but are able to communicate via WiFi and WiFi-Direct). They exchange coordination messages via WiFi-Direct and determine that Traveler 4 and 5 have the same mobility requirements/preferences while Traveler 6 requires a wheelchair accessible vehicle. Traveler Group 3 is comprised of Traveler 4 and Traveler 5 while Traveler Group 4 is comprised of Traveler 6.

34. The mobile device of Traveler 4 broadcasts a Personal Mobility Messages (PMM) via WiFi-Direct. The requests include:

   a. Message 1 (Traveler Group 3):
      a. A request ID (randomly generated identifier):
      b. Transport Preference: Transit Bus
      c. Number of Travelers: 2
      d. Mobility Requirements:
         i. Regular Seat (2)
         ii. Handicap seat (0)
         iii. Wheelchair Access (0)
         iv. Standing (0)
         v. No Preference (0)
      e. Departure Time: Now
      f. Origin: Transit Stop B (latitude, longitude)
      g. Destination: Transit Stop C (latitude, longitude)
   b. Message 2 (Traveler Group 4):
      a. A request ID (randomly generated identifier):
      b. Transport Preference: Transit Bus
      c. Number of Travelers: 1
      d. Mobility Requirements:
         i. Regular Seat (0)
         ii. Handicap seat (0)
         iii. Wheelchair Access (1)
         iv. Standing (0)
         v. No Preference (0)
      e. Departure Time: Now
      f. Origin: Transit Stop B (latitude, longitude)
      g. Destination: Transit Stop C (latitude, longitude)

35. The Transit Stop B RSE receives the Transit Ride Request Messages and relays them to the Ride Request Database Service via backhaul.

36. The Transit Dispatch Center receives the PMMs from the Ride Request Database Service and relays them to the next transit vehicle (Transit Vehicle A) approaching the transit stop.

37. Transit Vehicle A receives the PMM and compares the Transit Ride Requests from Traveler 4's mobile device against its on-board capacity database.

a. Transit Vehicle A determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.

38. Transit Vehicle A broadcasts the following messages to the Transit Dispatch Center which relays the message to the Transit Stop B RSE which relays the messages to Traveler 4's mobile device via WiFi-Direct.

a. Transit Availability Acknowledgment Message (Traveler Group 3):
   a. Vehicle: Transit Vehicle A
   i. Availability – "Available"
   ii. Regular seats (2)
   iii. Handicap seat (0)
   iv. Wheelchair access (0)
   v. Standing (0)

b. Transit Queued Traveler Request (Traveler Group 4)
   a. Availability – "Not enough capacity for your group. Reserved Position 1 on Next Transit Vehicle"
   b. Queue Position ID: 1
   c. Number of Travelers (1)
   d. Regular seats ()
   e. Handicap seat (0)
   f. Wheelchair access (1)
   g. Standing (0)
   h. No preference (0)

39. Traveler 4's mobile device communicates the above messages to all travelers at Transit Stop B through coordination messages sent via WiFi-Direct.

40. The Transit Dispatch Center sends a Transit Queued Traveler Request to Transit Vehicle B via cellular on behalf of Traveler 6 that includes the Queue Position ID and requested seats:

a. Queue Position ID: 1
b. Number of Travelers (1)
c. Regular seats ()
d. Handicap seat (0)
e. Wheelchair access (1)
f. Standing (0)

41. Transit Vehicle B receives the Transit Traveler Queued Traveler Request and compares the against its on-board capacity database.

   a. Transit Vehicle B determines optimal seating/standing configuration based upon the received Transit Ride Requests and available current capacity.

42. Transit Vehicle B broadcasts the following messages to the Transit Dispatch Center which relays the message to the Transit Stop B RSE which relays the messages to Traveler 4's mobile device via WiFi-Direct.

   a. Transit Availability Acknowledgment Message (for Traveler 6):
      a. Vehicle: Transit Vehicle B
      vi. Availability – "Available"
      vii. Regular seats (2)
      viii. Handicap seat (0)
      ix. Wheelchair access (0)
      x. Standing (0)

43. Traveler 4's mobile device communicates the above messages to Traveler 6 at Transit Stop B through coordination messages sent via WiFi-Direct.

44. Prior to arriving at the Transit Stop, Transit Vehicle A notifies Traveler Group 1 (Traveler 1 and Traveler 2) that his/her stop is approaching.

45. Transit Vehicle A arrives at Transit Stop B.

46. Traveler Group 1 (Traveler 1 and Traveler 2) disembarks from Transit Vehicle A. Upon exiting Transit Vehicle A, the mobile devices of Traveler 1 and Traveler 2 resume sending PSMs.

47. The mobile device of Traveler 1 coordinates with Transit Vehicle A and acknowledges that Traveler 1 and traveler 2 are no longer passengers on-board Transit Vehicle A.

48. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

   a. Regular Seating – 2
   b. Handicap seating – 0
   c. Wheelchair access – 0
   d. Standing – 13

49. Traveler Group 2 (Traveler 4 and Traveler 5) board Transit Vehicle A

50. The mobile device of Traveler 4 coordinates with Transit Vehicle A and acknowledges that Traveler 4 and Traveler 5 are passengers on-board Transit Vehicle A.

51. Transit Vehicle A updates its on-board capacity database to indicate the current available capacity:

   a. Regular Seating – 2
   b. Handicap seating – 0
   c. Wheelchair access – 0
   d. Standing – 13

52. The mobile device of Traveler 4 coordinates with the mobile device of Traveler 6 and passes communication responsibility for Traveler 6 to Traveler 6's mobile device.

53. Transit Vehicle A departs Transit Stop B and heads towards Transit Stop C while broadcasting BSM and Vehicle Probe messages.

54. Transit Vehicle B arrives at Transit Stop B.
55. Traveler 6 boards Transit Vehicle B.
56. Traveler 6's mobile device coordinates with Transit Vehicle B and acknowledges that Traveler 6 is a passenger on-board Transit Vehicle B.
57. Traveler 6's mobile device ceases to broadcast PSM and PMM messages.
58. Transit Vehicle B departs Transit Stop B broadcasting BSM and Vehicle Probe message.
59. These steps repeat at different stations.

7.4 Large-Scale Scenarios

The intent of the Large-Scale Field Test is to replicate the Small-Scale Field Test, but in an uncontrolled and naturalistic environment. More specifically, to provide situations where a variety of different nomadic devices join, interact, separate, re-join, etc. during real-life daily travel by participants. This experimental field test is focused on obtaining substantive research results in a real-world environment using an existing, operational transit system, and recruiting regular users of these transit services as study participants. The large-scale test will be conducted at a university with transit vehicle services and recruited university staff as participants with DSRC equipped mobile devices.

The university, which is continuously experience growth, has developed a strategy for accommodating the thousands of staff and visitors that travel to/from the multiple buildings and locations on campus on a daily basis. High among the approaches to support this need are the use of remote parking, particularly for staff, to allow for the lots and parking garages closer in proximity to the university buildings to be used by visitors and others, and a park-once philosophy for visitors that provides for university-operated shuttles to move visitors between parking garages and various other facilities, some located more than 1.0 miles away. To enable the efficient movement of these people, a university must operate at least one distinct service.

During the course of a normal week, staff typically work regular shifts, consisting of several hundred regular customers. These buses will have DSRC, LTE and WiFi capabilities. Similar to the small-scale test, passengers will transition between pedestrian and rider when boarding and alighting these buses.

All of these vehicles as well as transit stops will be outfitted with connected vehicle technology and operated for several weeks. This will create the potential for many if not all of the various types of scenarios and interactions that are described in the Small-Scale demonstration, but in a naturalistic setting. Table 7.2 summarizes the major elements and technology interaction events presented in the small-scale scenarios and how these types of events will be realized as part of the large-scale demonstration.

Table 7.2. Major Elements and Technology Interaction Events Expected in the Large Scale Demonstration

Small Scale Scenario	Interaction Element	How this will be Observed During the Large-Scale Demonstration
Scenario 1 – Taxi, Limo, Rideshare	Individual travelers utilizing ride-sharing, taxi, and/or limo service	• Co-workers at the university use ridesharing to travel to the university facilities or to the remote parking lot • Late-night on-demand transit service from/to university buildings and remote parking
	Individual traveler creates safety situation requiring PSM to alert on-coming vehicles that they are in or near the roadway	University staff routinely cross the main road to reach near-building parking representing an opportunity for pedestrian warning PSMs to be utilized.
Scenario 2 – Large Crowd, Multiple Vehicles	Large crowd of travelers flooding a transit stop location	Many university staff work regular shifts providing for natural “bunching” or grouping of travelers at specific transit stops near the remote parking (am) and near the university buildings (pm).
	Capacity limitations/queuing of travelers	Natural groupings of arrival/departure times around the beginning and ending of shifts creates capacity limitations/queuing opportunities
Scenario 3 – Multiple Vehicles, Multiple Stops, On/Off Pedestrians	Multiple travelers at one transit stop going to different destinations	Several transit stops are shared between the different transit vehicles.
	Passengers boarding and disembarking throughout the trip across several transit stops.	Riders who take the transit vehicles have the opportunity to board/disembark at several stops that circle the university buildings creating an opportunity to observe on/off behavior.

Source: Battelle

Chapter 8 Summary of Impacts

The impacts of the introduction of mobile devices as described in this concept of operations is not completely known. This is a key research question of the project. However, it is expected that the introduction of mobile devices, equipped with DSRC, will result in the identification of issues associated with the technology's ability to communicate across a spectrum of potential protocols (WiFi, cellular, DSRC).

8.1 Operational Impacts

The small-scale demonstration will be in a semi-controlled environment under research conditions and will therefore have only minor impact operationally. Similarly in the large-scale demonstration there will be no changes to the operations of the transit vehicles. In either demonstration, the vehicle operators will utilize their standard procedures for operating their vehicles and passengers will use and carry mobile devices in a fashion similar to what they would under non-test conditions.

8.2 Organizational Impacts

This research may result in the need for modifications to existing standards governing message sets and communication protocols for mobile devices and for connected vehicles. The organizations governing, developing, and/or overseeing implementation of these standards may need to include the results of this research in future discussions and plans.

8.3 Impacts During Development

Aside from the impacts to the connected vehicle technology efficiency and effectiveness discussed above, there should be no other impacts during the demonstrations or during the development of the demonstrations.

Chapter 9 Analysis of the Proposed System

9.1 Summary of Improvements

Individual communication devices (e.g., mobile devices) have not been widely included in existing connected vehicle research and demonstrations. In cases where such devices were included, such as in the demonstration of Prototype Intelligent Network Flow Optimization (INFLO) Dynamic Speed Harmonization and Queue Warning, these mobile devices, referred to in that study as “nomadic devices,” were operated under the constraint that they were the only connected device in the vehicle (i.e., the vehicle was not also a connected vehicle).

Including mobile devices more holistically within the connected vehicle environment will ultimately:

- Improve the mobility of individual travelers
- Improve the safety of individual travelers
- Improve the efficiency of the various communication systems, particularly DSRC, by allowing for adjacent communication protocols to occur within devices (i.e., distributed processing model) and allowing once device to communicate on behalf of many when appropriate.

While these are the ultimate objectives of integrating mobile devices into the Connected Vehicle environment, the proposed experimental prototype system (EPS) developed within this project is a research system where a limited set of needs and functions are being researched to serve as the basis for further research. The approach taken within the project was:

1) Development of the ultimate User Needs, shown in Chapter 6 above, that define the needs to be addressed to integrate mobile devices in the CV environment.
2) Development of the corresponding System Requirements, to be developed within the Systems Requirements document.
3) Selection of a subset of the System Requirements, to be indicated in the System Requirements document, which will be deployed within the Small-Scale and Large-Scale Demonstrations. The selection of this subset is based on the fundamental research needs as well as on funding limitations.

9.2 Disadvantages and Limitations

The ubiquitous nature of smartphones and other mobile devices in today’s world makes their integration a virtual necessity for any communication-based system that is being planned for wide scale adoption. However, requiring DSRC integration into mobile devices will present some challenges that will require additional resources, standards, message sets, and firmware/software to accomplish. For example, at a minimum, adding additional chipsets and another wireless antenna and radio will likely increase the form factor of the mobile device as well as increasing the power draw on the device battery. In the short term, these obstacles may make the initial benefits of including DSRC technology in mobile devices, along with ad-hoc coordination between mobile devices and between mobile devices and vehicles, difficult to observe in anything but test conditions.

This project should be viewed as the first one in a series of research projects to address the needs of vulnerable road users and be expanded to include the different operational behaviors of bicycles. There will other challenges such as the following that will need to be investigated and resolved via future projects to create a true integration of mobile devices into the CV environment:

- What DSRC Channel will be used for broadcasting PSMs and other mobile device-initiated message types that are transmitted over DSRC?
- Will DSRC Channel congestion be an issue that must be addressed? And if so, how can this be accomplished?
- How can OEMs / vehicle manufacturers be enticed to broadcast other message types beyond those that are mandated, i.e., BSM, Part I only?
- How can trip request data that has different destination location information, but is on the potential path of another traveler's trip request be coordinated / be combined into one PMM?
- How can the location determination accuracy of a mobile device be improved? How can the battery life of a mobile device be maintained while achieving higher accuracy?
- How can the sometimes-erratic movements of pedestrians be accounted for in determining a mobile device's path prediction (beyond that of the predictions based on destination location and mobile device path history)?

9.3 Alternatives and Trade-Offs Considered

There are two main alternatives to a coordination integration of mobile devices into the connected vehicle environment. First, mobile devices could not include DSRC communications, but rely upon existing communication protocols commonly found in mobile devices for coordination messages as well as interacting with vehicles and infrastructure components. This alternative has the significant appeal in that only minimal new message sets, standards, and hardware/firmware would need to be developed. However, this alternative would also forgo the potential benefits of low-latency communication between vehicles and pedestrians or between infrastructure components and pedestrians (safety-centric applications).

A second alternative would be to continue to allow mobile devices to exist within the connected vehicle environment in an uncoordinated fashion. That is, maintain the currently envisioned connected vehicle environment. This has the benefit of not requiring any new hardware/firmware, standards, etc. to be developed and adopted. However, this alternative would likely not realize any of the benefits associated with coordination. Additionally, if mobile devices do begin to utilize DSRC communications, this could result in inefficiencies and increased requirements for connected devices to process new message types, which will require significant resources to achieve.

Appendix A Acronyms and Abbreviations

Acronym	Description / Explanation
Android	Google-based Operating System
API	Application Program Interface
ASC	Actuated Traffic Signal Controller
ATIS	Advanced Traveler Information System
BSM	Basic Safety Message
ConOps	Concept of Operations
CVRIA	Connected Vehicle Reference Implementation Architecture
DCM	Data Capture and Management
DMA	Dynamic Mobility Applications Program
DSRC	Dedicated Short Range Communications
EnableATIS	Enabling Advanced Traveler Information System
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GPS	Global Positioning System
GSM	Global System for Mobile Telecommunications
I2P	Infrastructure-to-Pedestrian
MAC address	Media access control address
NTCIP	National Transportation Communications for ITS Protocols
OS	Operating System
OSU	Ohio State University
P2I	Pedestrian-to-Infrastructure
P2V	Pedestrian-to-Vehicle
PCW	Pedestrian in Signalized Crosswalk Warning Application
PED-SIG	Mobile Accessible Pedestrian Signal Systems
PMM	Personal Mobility Message
POV	Personally Owned Vehicle
PSM	Personal Safety Message

Acronym	Description / Explanation
R.E.S.C.U.M.E	Response, Emergency Staging, Communications, Uniform Management, and Evacuation
RFID	Radio Frequency Identification
SAE	Society of Automotive Engineers
SET-IT	Systems Engineering Tool for Intelligent Transportation
SPaT	Signal Phasing and Timing
SSID	Service Set Identifier
SysRS	System Requirements
TCP/IP	Transmission Control Protocol/Internet Protocol
TOC	Transportation Operation Center
TMC	Transportation Management Center
TrMC	Transit Management Center
U.S. DOT	U.S. Department of Transportation
UDP	User Datagram Protocol
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
VSM	Vehicle Situation Data Message
WiFi	Wireless Fidelity

Appendix B Terms and Definitions

Term	Definition
Accelerometer	Hardware sensor that measures the acceleration force on the device along three axes.
Android	Google's operating system. Naming convention incorporates sweets (i.e., éclair, donut)
Barometer	Hardware sensor that measures the pressure of air surrounding the device.
Basic Safety Message (BSM)	Connected vehicle message type which contains vehicle safety-related information that is broadcast to surrounding vehicles;
Bluetooth	Short range wireless technology used to exchange data between enabled devices which are paired (establishing a connection between two Bluetooth 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.
Driver	For the experimental prototype systems project, driver refers to operators of light-duty and transit vehicles. However, theoretically the application would be appropriate to operators of any type of vehicle.
DSRC	Dedicated Short-Range Communications; a low-latency, high-reliability, two-way communications tool used for sending transportation safety messages.
Emergency Vehicle Alert Message	Connected vehicle message type which is used to communicate warnings to surrounding vehicles that an emergency vehicle is operating within the vicinity;
Fragmentation	Occurrence in which mobile device users are operating on different versions/releases of a device's operating system.
Gravity (Sensor)	Software sensor that estimates the force of gravity along the three axes.
Gyroscope	Hardware sensor that measures the rate of rotation of the device along three axes.
Hygrometer	Hardware sensor that measures the humidity of the air surrounding the device.
Light Sensor	Hardware sensor that measures ambient light.
Linear Acceleration	Software sensor that estimates the acceleration force of the device along three axes, excluding gravity.
Link	A trip chain phase in which the traveler is in transit.

Term	Definition
Magnetometer	Hardware sensor that measures the geomagnetic field surrounding the device along 3 axes.
Message Type	Type of personal safety or personal mobility message that is transmitted based on the technology used and level of coordination available.
Mobile Hardware Sensor	Reports raw data from a particular sensor on the mobile device
Mobile Network	A wireless radio network distributed over a large geographic area with fixed location transceivers spread across it. These receivers work together to provide radio coverage over the entirety of the geographic area allowing a large number of mobile devices to communicate with each other.
Mobile Software Sensor	Interprets data from one or more hardware sensors to provide an imputed output
National ITS Architecture	Common framework for the planning, development and integration of ITS deployments.
NFC	Near Field Communications; short-range communications technology (typically 1-2 inches) that may be used to make payments via mobile devices.
Node	A trip chain phase in which the traveler is located at a transition point, such as a bus stop or train station.
Not Transmitting	The state in which a mobile phone user has not opted in to exchanging safety and mobility messages
Operating System	The prerequisite mobile device software (e.g. Android, iOS, etc.) that manages all other applications.
Opt-In	User action required to begin transmission of safety and mobility messages via mobile device.
Opt-Out	User action required to end transmission of safety and mobility messages via mobile device.
Origin	The starting point of a traveler’s trip.
Personal Mobility Message (PMM)	Similar to PDM, message intended for the exchange of mobility messages between individual travelers and vehicles/infrastructure, via mobile device.
Personal Safety Message (PSM)	Similar to BSM, message intended to transmit low-latency, urgent safety messages between individual travelers and vehicles/infrastructure, via mobile device
Proximity	Hardware sensor that measures the distance between the sensor and a nearby object.
Road Condition Message	Connected vehicle message type which provides information on roadway surface conditions, such as the presence of ice

Term	Definition
Rotation Vector	Software sensor that describes the orientation of the screen of a mobile device.
Step Detector/ Counter	Software sensor that uses accelerometer data to estimate when a step has been taken.
System Engineering Tool for Intelligent Transportation (SET-IT)	A single software tool that integrates drawing and database tools with the Regional Unified Model Architecture so that users can develop project architectures for pilots, test beds and early deployments.
Thermometer	Hardware sensor that measures he temperature of air surrounding the device.
Transmitting	The state in which a traveler has opted in and is sending/receiving messages via mobile device
Traveler advisory message	Connected vehicle message type which Provides congestion, travel time, and signage information.
Trip Chain	A term used to describe the duration of a trip from origin to destination, including all nodes and links that a traveler encounters.
Trip Chain Phase	A duration of a trip chain in which a traveler is either at a node or traveling within a link. A phase can only include a node or a link, not both.
Uncoordinated	Messages are coordinated when one or more mobile devices have boarded a single vehicle (i.e. multiple passengers have boarded a bus), and are interpreted as a single, cohesive sender/recipient.
Weather Condition Message	Connected vehicle message type which communicates area specific weather information
WiFi	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 either a pedestrian is in the area, a pedestrian is in the path of collision, or a collision is imminent and issue either an advisory, an alert, or 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 broadcast range can be describe in text form as

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

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 1 second)
- PRT is driver Perception Reaction Time (seconds) (assumed equal to 2.5 seconds)[16]
- 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 advisories, alerts and, warnings that are issued. Some of these variables are discussed below.

[16] 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.[17] 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[18] 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, Warning, and Stop! 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)

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

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

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

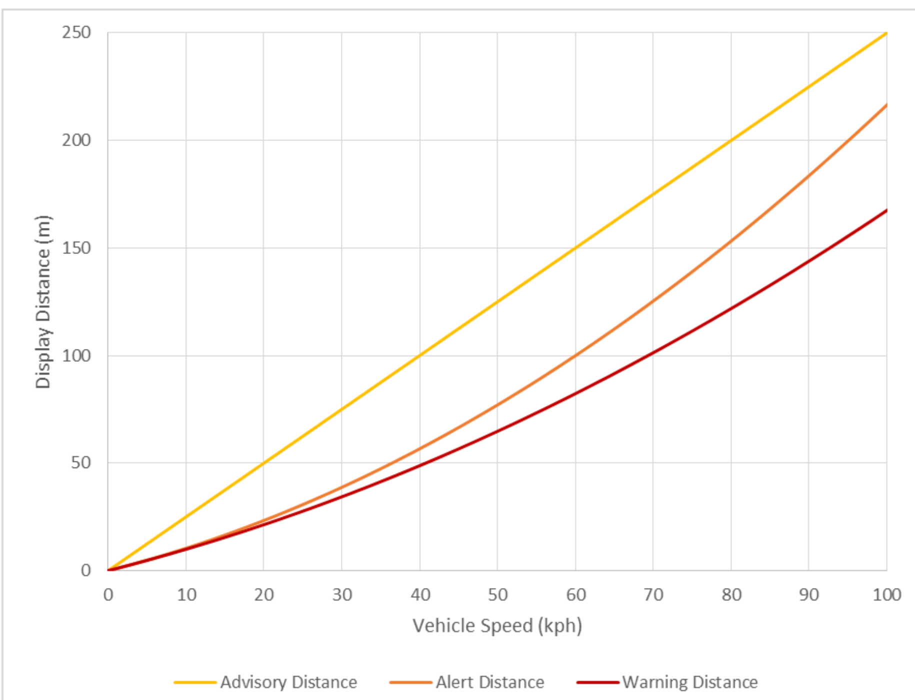
$$d_{alert} = 1.1 * \left\{[(0.5 + 2.5) * v] + \frac{v^2}{2(3.4)}\right\}$$

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

Where

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

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



Source: Battelle

Figure C-1: Message Display Distances

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Federal Highway Administration

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FHWA-JPO-16-422
July 2016